ASD-TR-61-426



# STUDY OF PRESSURE PACKING TECHNIQUES FOR PARACHUTES

TECHNICAL REPORT NO. ASD-TR-61-426

June 1962



Flight Accessories Laboratory
Aeronautical Systems Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

Project No. 8151, Task No. 60151

(Prepared under Contract No. AF 33(600)-39643
by Space Recovery Systems, Inc., El Segundo, California)

## NOTICES



200 - August 1962 - 45-2021 & 2022

## FOREWORD

This report was prepared by Space Recovery Systems, Inc., a division of Itek Corporation, under sub-contract from the M. Steinthal and Company, Inc. The work was initiated under USAF Contract No. AF 33(600)-39643 by Headquarters, Wright Air Development Center, Directorate of Laboratories, Aeronautical Accessory Laboratory (now Flight Accessories Laboratory), with Captain Latham as Project Engineer.

The work at SRS was performed by R. C. Birdwell, W. J. Chagaris, B. C. Jenkins, and J. V. Waite, under supervision of T. W. Knacke. O. W. Sepp monitored the contract at M. Steinthal and Company, Inc.

## ABSTRACT

This report summarizes the results of a parachute pressure packing investigation designed to find optimum parachute volume reduction techniques. Included are a description of the test equipment and a discussion of the influence of parachute types, time rate of pressure application and container shapes on the pack density. The results are presented in graph form.

The study revealed that pressure packing using a mechanical press can reduce the volume of a good hand-packed parachute by approximately fifty percent under application of about 100 PSIG of pressure. This results in a pack density of 45 pounds per cubic foot. The obtained pack densities are independent of parachute type and time rate of pressure application.

## PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

George A. Solt, Jr.

GEORGE A. SOLT, JR.
Chief, Retardation and Recovery Branch
Flight Accessories Laboratory

# TABLE OF CONTENTS


| | | | Page No. |
|---|---|---|---|
| I. | INTRODUCTION | | 1 |
| II. | TEST PROCEDURE | | 3 |
| | 1. | General Scope | 3 |
| | 2. | Test Equipment | 3 |
| | 3. | Uncompressed Volume | 4 |
| | 4. | Packing Rate | 4 |
| | 5. | Mechanical Packing | 5 |
| | 6. | Vacuum Packing | 5 |
| | 7. | Vacuum-Mechanical Packing | 6 |
| | 8. | Lace Packing | 6 |
| III. | DISCUSSION OF TEST RESULTS | | 7 |
| | 1. | The Effect of Pressure Packing Rate | 7 |
| | 2. | The Effects of Parachute Type | 7 |
| | 3. | The Effect of Bag Size and Shape | 8 |
| | 4. | Mechanical Packing | 8 |
| | 5. | Vacuum Packing | 9 |
| | 6. | Lace Packing | 9 |
| | 7. | Combined Mechanical and Vacuum Packing | 10 |
| | 8. | Volume Growth after Packing | 10 |

TABLE OF CONTENTS (Cont'd.)


| | | Page No. |
|---|---|---|
| IV. | SUMMARY | 12 |
| V. | RECOMMENDATIONS FOR A CONTINUED STUDY | 14 |
| VI. | DEFINITION OF TERMS | 16 |
| APPENDIX I | ILLUSTRATIONS | 17 - 45 |
| APPENDIX II | EFFECTIVE PACKING PRESSURE | 46 |

## LIST OF ILLUSTRATIONS


| Figure | | Page |
|---|---|---|
| 1 | Uncompressed Volume Test Data, Solid Flat Parachute, 1.0 PSI | 18 |
| 2 | Uncompressed Volume Test Data, Ribbon Parachute, 1.0 PSI | 19 |
| 3 | Uncompressed Volume Test Data, Solid Flat Parachute, 2.5 PSI | 20 |
| 4 | Uncompressed Volume Test Data, Ribbon Parachute, 2.5 PSI | 21 |
| 5 | Mechanical Pressure Packing Equipment | 22 |
| 6 | Pressure Packing Test Data, Solid Flat Parachute, 15-Second Increments | 23 |
| 7 | Pressure Packing Test Data, Solid Flat Parachute, 1-Minute Increments | 24 |
| 8 | Pressure Packing Test Data, Solid Flat Parachute, 5-Minute Increments | 25 |
| 9 | Pressure Packing Test Data, Ribbon Parachute, 15-Second Increments | 26 |
| 10 | Pressure Packing Test Data, Ribbon Parachute, 1-Minute Increments | 27 |
| 11 | Pressure Packing Test Data, Ribbon Parachute, 5-Minute Increments | 28 |
| 12 | Test Results, Volume vs Pressure, Solid Flat Parachute | 29 |
| 13 | Test Results, Percent Volume vs Pressure, Solid Flat Parachute | 30 |
| 14 | Test Results, Density vs Pressure, Solid Flat Parachute | 31 |
| 15 | Test Results, Volume vs Pressure, Ribbon Parachute | 32 |

LIST OF ILLUSTRATIONS (Cont'd.)


| Figure | | Page |
|---|---|---|
| 16 | Test Results, Percent Volume vs Pressure, Ribbon Parachute | 33 |
| 17 | Test Results, Density vs Pressure, Ribbon Parachute | 34 |
| 18 | Test Results, Volume vs Pressure, 10-Foot Ribbon Parachute | 35 |
| 19 | Test Results, Density vs Pressure, 14-Foot Ribbon Parachute | 36 |
| 20 | Laced Pack Volume vs Packing Method | 37 |
| 21 | Laced Pack Percent Volume vs Packing Method | 38 |
| 22 | Laced Pack Density vs Packing Method | 39 |
| 23 | Combined Mechanical and Vacuum Pressure Packing, Volume vs Pressure | 40 |
| 24 | Combined Mechanical and Vacuum Pressure Packing, Percent Volume vs Pressure | 41 |
| 25 | Combined Mechanical and Vacuum Pressure Packing, Density vs Pressure | 42 |
| 26 | Mechanical Pack Growth vs Time, 10-Foot Ribbon Parachute | 43 |
| 27 | Pressure Packing Container Ratio and Dimensions | 44 |
| 28 | Mechanical Packing Pressure Distribution | 45 |

## I. INTRODUCTION

Conventional hand packing of parachutes results in a pack density of approximately 20 pounds per cubic foot. It is often required to increase this value due to limitations in parachute storage volume. Pressure packing and lace packing have been used previously to reduce the parachute volume. No systematic test program had ever been conducted to determine the amount of practical volume reduction and the influence of pressure packing on parachute performance. In addition, the influence of different parameters on the volume reduction had not been clearly established. These parameters are parachute type, container shape, deployment bag, method for applying pressure, time rate of applying pressure, and growth of the parachute pack after release of pressure.

The study of pressure packing techniques for parachutes, as initiated by WADD, consists of a multiphase program with the goal of testing the optimum packing methods during a drop test program.

This report presents a preliminary investigation, supported by the necessary testing, to determine practical packing forms, deployment bags, pressure application equipment, and application techniques.

In addition, the design and fabrication of packing forms, deployment bags, and pressure applicators are recommended as required for equipment and techniques applicable to field packing operations.

Three basic methods of parachute packing were investigated.

(1) Mechanical pressure, as applied with a hydraulic cylinder and piston.

(2) Vacuum pressure, as applied by the atmosphere upon an evacuated bag containing the parachute.

(3) Lace pressure, as applied to the parachute when tensing circumferential cords on a parachute bag.

The volume decrease achieved by these three methods is compared to the volume of a standard hand-packed parachute of similar size and type.

---

Manuscript released by the author August 1961 for publication as an ASD Technical Report.

The major portion of testing was accomplished with two heavy-duty ribbon parachutes and one lightweight, solid flat type parachute. Complete parachutes were used on all tests. No canopy alone or suspension lines alone tests were accomplished. For mechanical packing no deployment bags, reefing rings or reefing line cutters were employed. A single cylindrical container provided a simple standard for packaging the parachutes under different pressure-time conditions, and a 10-ton hydraulic press was used to provide most of the pressure packing data.

## II. TEST PROCEDURE

### 1. General Scope

The four methods used to reduce parachute volume were:

a. The application of pressure by means of a hydraulic piston;

b. The application of pressure by the atmosphere on an evacuated bag containing the parachute;

c. The application of pressure by circumferential tensing of laces around the parachute bag pack; and

d. A combination of hydraulic piston pressure on a parachute pack and, at the same time, the evacuation of air from the pack by means of a vacuum pump.

In each case, the tests were intended to establish volume-pressure relationships. Comparison of these relationships for the various packing methods would provide a basis upon which an optimum selection could be made. Once this had been accomplished, the most favorable method could receive concentrated development.

### 2. Test Equipment

The following list and description of equipment and material was used in the parachute pressure packing investigation.

One - 10-ton hydraulic pressure packing press
One - 1.15 cubic foot cylindrical steel container, clam shell type, 10-inch inside diameter x 25-inch deep
One - Vacuum pump
One - Mercury Manometer board
Polyethelene film, 6 Mil thickness
Polyester film (DuPont "Saran"), 2 Mil thickness
Barrier material, MIL-R-131C
One - Cylindrical, lace type deployment bag
Miscellaneous items, such as tape, heat sealer, scissors, hydraulic pressure gauges, etc.

3. <u>Uncompressed Volume</u>

Two series of tests were conducted, utilizing both solid and ribbon parachutes, to determine the optimum pressure necessary for the establishment of an initial or uncompressed volume. The first test series determined the deviation from a mean volume with an applied pressure of 1.0 PSIG applied for a period of one hour (see Figures 1 and 2), while the second series gave identical information at 2.5 PSIG applied pressure also for one hour (see Figures 3 and 4). While a pressure level of 1.0 PSIG proved to be unsatisfactory, 2.5 PSIG produced consistent results. It was assumed that the 2.5 PSIG initial pressure level also approximates common hand-packing densities. For this reason, the 1.0 PSIG pressure specified in the contract was not adhered to and, for the purposes of this report, the parachute volume at a pressure of 2.5 PSIG is defined as the uncompressed parachute volume. The position of the hydraulic piston is measured at the 2.5 PSIG point as a zero reference upon which further volume changes can be based. As the pressure was increased, the change in piston position was measured and later plotted in terms of volume changes. The volume-piston position relationship is:

$$\Delta V = \pi r^2 h$$

where $\Delta V$ = volume reduction
$h$ = piston movement from the zero reference position
$r$ = piston radius

The change in parachute volume relative to the uncompressed volume is expressed as a percent decrease or:

$$\phi = \frac{\Delta V}{V_u} \times 100 = \frac{V_u - V_c}{V_u} \times 100$$

where $\phi$ = parachute volume reduction factor
$V_u$ = initial uncompressed volume
$V_c$ = compressed parachute volume

4. <u>Packing Rate</u>

The effect of the compression rate on the decrease in parachute volume was determined by:

a. Continuous change of applied pressure from zero to maximum within a specified time;

b. Incremental change of applied pressure at fixed time intervals.

The time increment between force change was constant for a given test run. Time increments of 15 seconds, 1 minute and 5 minutes were employed. A varying pressure increment was used in order to acquire accurate data in the critical portion of the pressure range. Starting with the established initial pressure of 2.5 PSIG, pressure increments were: 10 pounds from 10 to 60 PSIG; 20 pounds from 60 to 100 PSIG; and 50 pounds from 100 to 200 PSIG.

5. Mechanical Packing

A 10-ton hydraulic press was used for most of the experiments. The test set-up is shown in Figure 5. A hydraulic cylinder is mounted vertically over the parachute container. The parachute to be pressure packed is folded into the steel container, canopy first, followed by suspension lines and risers. No deployment bag is used. A thick wooden disc (in the case of a cylindrical pressure packing container) is placed on the top. This acts both as a cap and as a base for the hydraulic piston to act upon. The hydraulic pressure is now increased until the disc pressure acting on the parachute amounts to 2.5 PSIG. After application of a constant pressure of 2.5 PSIG for one hour, the piston position is recorded to determine the uncompressed volume before starting the actual compression test. All parachutes were packed into a steel cylinder with a total volume of 1.15 cubic feet. This container is hinged so as to open in a clam shell fashion. A hinged opening is necessary since the parachute is tightly wedged by the pressure packing forces. The 10-ton press is capable of applying 200 PSIG on the 10-inch diameter cylinder.

6. Vacuum Packing

Two methods of vacuum reduction of parachute volume were investigated. The first method removes the air contained inside of a steel cylinder through holes in the base of that cylinder. The parachute inside is compressed by the action of atmospheric pressure. A loose plastic film sealing the open top of the cylinder is free to lay and press upon the parachute. The second method is to place the entire parachute within a plastic bag and evacuate the air. By this means, pressure is uniformly exerted upon the parachute pack from all directions. Volume changes, for the second method of vacuum packing, were measured by water displacement methods. This type of measurement was necessary since vacuum bag packages tend to be irregular in shape.

7. <u>Vacuum-Mechanical Packing</u>

To find if a greater volume reduction could be obtained by use of a combined vacuum and mechanical method, a parachute was placed inside of a 10-inch diameter test container having a vacuum outlet tube on the bottom. In this test series, the initial parachute volume was measured at 2.5 PSIG hydraulic pressure. The vacuum pump was then started, bringing the applied pressure to 25 inches of mercury. With the vacuum pump running, the hydraulic pressure was increased, in steps, up to 200 PSIG. A variation of this procedure was to bring the hydraulic pressure up to maximum and then start the vacuum pumping process.

8. <u>Lace Packing</u>

Volume reduction by deployment bag lacing is considered worthwhile since it is simple and can be accomplished with a minimum of equipment. The design of the deployment bag and manner of lacing are very important in this type of pressure packing. A well reinforced cylindrical deployment bag with circumferential cross-lacing is required. There are many variables in lace packing since it is a hand operation. The following operation is typical of the procedure used.

A split cylindrical-shaped deployment bag is employed. Two rows of metal grommets, directly opposed, run along the length of the bag. Prior to installation of the parachute, the bag is formed into an oversized cylinder shape by loosely lacing a nylon cord through consecutive grommets on either side. The parachute is folded into the loose bag. Reduction is then accomplished by successive tightening of each cord lace. A mechanical advantage type hand tool with a 16-inch lever arm is used to tense the laces. Other hand tools such as hooks and paddles are used only as a means to prevent hand injury. The procedure for lace packing is generally slow and strenuous.

## III. DISCUSSION OF TEST RESULTS

### 1. The Effect of Pressure Packing Rate

The results of the packing rate tests are shown in Figures 6 through 8 for a lightweight solid canopy parachute, and Figures 9 through 11 for a heavy duty ribbon parachute. A study of the figures mentioned shows the rate of pressure packing force to have negligible effect on volume reduction. The rate tests were conducted with the mechanical pressure packing equipment and without parachute deployment bags.

### 2. The Effects of Parachute Type

A series of tests was conducted to ascertain if the parachute type had an effect on the ultimate pressure pack density. The parachutes used for these tests were:

a. An 8-foot nominal diameter, heavy duty, ribbon parachute with 1,000 pound horizontal ribbon; an uncompressed volume of 0.73 cubic feet, a weight of 16 lbs., and a suspension line length to diameter ratio of 1.0.

b. A 34.5 -foot nominal diameter, lightweight, solid flat parachute with a 1.1 ounce per square yard canopy, an uncompressed volume of 0.73 cubic feet, a weight of 20.5 lbs., and a suspension line length to diameter ratio of 1.0.

Both parachutes, when pressure packed under similar conditions, were reduced to a density of 45 pounds per cubic foot at maximum pressures. A comparison of Figures 6 through 17 illustrates that the pressure-volume function difference between these two parachutes is of no practical concern. Figures 14 and 17 show the corresponding pack densities versus applied pressure. It is apparent that the parachute type does not influence the pack density which can be achieved at different degrees of pressure.

A 10-foot nominal diameter heavy duty parachute was used in initial tests. This parachute occupied an uncompressed volume of 0.97 cubic feet, weighed 24 pounds, and had a suspension line length to nominal diameter ratio of 1.5. Such a ratio was felt to be unrepresentative of standard parachute design and for final tests the 8-foot parachute with a suspension line to diameter ratio of 1.0 was substituted. Figure 18 presents the volume-pressure relationship obtained from tests of the 10-foot ribbon parachute.

Some testing was also accomplished using a 14-foot nominal diameter heavy duty ribbon parachute which weighed 85 pounds. A plot of density vs pressure for this parachute is shown in Figure 19.

3. The Effect of Bag Size and Shape

The shape and ratio of the geometric form of the pressure packed items have a strong effect on the maximum pack density. Pressure packed forms investigated were cylinders, rectangular boxes, and a wedge shape. The most efficient shape for pressure packing is the cylinder, and the most practical length is from one to two times the cylinder diameter. These ratios provide a good canopy and suspension line distribution and also avoid excessive wall friction always present in long cylinders. The most prominent advantage of a cylindrical bag is the ability to withstand strong forces without excessive deformation. The rectangular box shapes are among the more difficult to pressure pack. The packing bag corners and edges make even distribution of the parachute difficult, and the bag flat surfaces tend to bulge excessively under the internal pressure. Rectangular shapes must, therefore, be packed in rigid containers if their form is to be maintained.

For irregular shapes, loose fitting deployment bags were found to be most suitable in achieving high pack density. Using loose fitting bags in pressure packing, however, does require packing containers duplicating the actual compartment, and retaining containers for prolonged shelf life. Closing off the loose bag is far simpler than on a tight bag pack. This applies particularly to rectangular and wedge shapes.

Although a loose fitting bag seems opposed to the concepts of pressure packing, it is emphasized that such a bag will result in better shape retention. When a parachute is packed into an irregular shaped tight bag, strong, non-uniform tensions develop on the bag causing unwanted distortions in shape. A parachute packed into an oversized bag will not develop any appreciable surface tensions.

When successive removal and installation of a pressure packed unit is required, an undersize cylindrical deployment bag provides the most successful shape for volume retention.

4. Mechanical Packing

Piston compression can reduce a parachute to less than 50% of its uncompressed volume. This corresponds to a pack density of 45 pounds per cubic foot. The characteristic pressure-volume curves resulting from the hydraulic press experiments are shown in Figures 6 through 17.

From these figures it can be observed that the pressure is most effective from 0-60 PSIG. The advantage of applying pressures greater than 100 PSIG is shown to be slight.

### 5. Vacuum Packing

The evacuation of air from within a parachute volume envelope results in an atmospheric compression force. Pressure packing by vacuum methods results in volume reductions nearly identical to those experienced when the equivalent pressures are used with mechanical packing. A 15 PSIA pressure acting on the parachute will reduce the volume by 25-30% and achieve pack densities of 30-33 $lbs/ft^3$.

Sea level growth effects of vacuum packed parachutes are negligible so long as the vacuum seal is maintained. However, the effect of taking a vacuum packed parachute and placing it in a reduced atmospheric pressure environment is uncertain and should be investigated. Likewise, the placing of a vacuum packed parachute into an increased pressure environment would further decrease the pack volume with uncertain growth results upon a return to atmospheric pressure.

A particular advantage of vacuum packing is in the packaging for shelf storage. A film material can replace the more bulky metal or plastic container and the vacuum used can serve to reduce the package volume, and also act as a preservative.

### 6. Lace Packing

The measurement of applied pressure when using lacing loop compression is difficult. For this reason, the results of lace compression are expressed in terms of human strength and tools. Lace packing can achieve densities equivalent to and greater than vacuum compression. Although lace compression is simple and effective, it is also time consuming, strenuous and subject to human packing variations. Lace packing by women can achieve 25% volume reductions, while lace packing by men can achieve up to 34% volume reductions. If special hand-packing tools are incorporated in order to increase leverage, hand-lacing volume reductions can reach 40%. Under lace type compression, the only volume growth is due to stretch in the packing bag fabric. Pack densities of 33 to 39 pounds per cubic foot can be attained by lacing methods. Figures 20 through 22 show the volume reduction, percent volume reduction and pack density versus the method of lace packing used. For the lace packing tests, the 8-foot nominal diameter, heavy duty ribbon parachute was used.

7. Combined Mechanical and Vacuum Packing

A series of tests were conducted with combined application of mechanical pressure and vacuum using the 34.5-foot diameter solid flat parachute. The pack density values obtained under pure mechanical packing procedures could not be increased by the combined method. Test results are shown in Figures 23, 24 and 25.

8. Volume Growth after Packing

When pressure packing a parachute, a certain amount of package growth occurs after the packing force is relieved. This is particularly true on fabric bag type containers that are packed by the hydraulic press method. Brief package growth data have been compiled on the three methods of pressure packing, the hydraulic compression of a parachute into a steel cylinder without a deployment bag, vacuum bag-packing of a parachute and lace packing of a parachute into a cylindrical deployment bag.

The characteristic curve of parachute volume growth would indicate the initial growth is due to the resilient nature of nylon. This resilience produces a parachute package with a constant internal pressure which deforms the nylon deployment bags and causes package growth. For this reason, bags made from fabrics with very little fiber stretch should be used in pressure packing applications.

a. Mechanical Pack Growth

Figure 26 shows the results of a 10-foot nominal diameter ribbon parachute without a deployment bag which has been pressure packed into a cylindrical container with an initial volume of 1.0 cubic foot. This is reduced to a volume of 0.66 cubic feet at a pack density of 37 lbs/ft$^3$. It can be seen that almost 50% of the volume reduction achieved is lost when the pressure is removed. Two-thirds of that loss occurs within the first two minutes after release of packing pressure. It is apparent that a means of preventing packing growth is worthwhile and equal in importance to the pressure packing itself.

b. Vacuum Pack Growth

Vacuum packing attains relatively low pack densities; as a result, the parachute material is in elastic compression not much different than that of the atmospheric compression. This permits a balance of forces to exist without strain. Therefore, the growth occurring in vacuum packing is less severe, since by the very nature of the method a constant atmospheric pressure is applied during the storage life of the article.

The plastic bag materials used to envelop the parachute for vacuum packing were 6 mil polyethelene, 2 mil polyester (Saran) and barrier material MIL-R-131c. Both the polyethelene and polyester plastic films proved inadequate for retaining a vacuum. The loss of vacuum through these materials is a result of their high vapor transmission characteristics.

c. Lace Packing Growth

Lace packing produces a constant tension of the deployment bag fabric and cords, which retard growth. Although the fabric bags will stretch after long standing, growth is slow and within 5% or 10% of the initial volume.

d. Combined Mechanical and Vacuum Pack Growth

A parachute packed by a combination of mechanical and vacuum packing and sealed by barrier material MIL-B-131c has been maintained in storage over a year without any appreciable evidence of growth.

## IV. SUMMARY

It is apparent from a comparison of test results that the percent of volume reduction and pack density achieved is independent of the pressure packing method, packing rate, and type of parachute being packed. The major variable is the ultimate pressure which each method is able to apply. Hydraulic, or mechanical devices may easily reach high pressure packing values with volume reductions of 50% and pack densities of 45 pounds per cubic foot attainable. However, when the applied pressure is released, up to 20% of that volume reduction can be lost due to elastic expansion forces unless restraints are applied immediately. Applied pressures in excess of 100 PSI are not advantageous.

The volume reduction which can be attained by vacuum packing methods is small, and a function of the external atmospheric pressure acting on the vacuum bag. So long as the vacuum is maintained on the packing bag, no growth occurs. Volume reductions at normal atmospheric pressures may reach 30% (33 $lbs/ft^3$) with vacuum methods. It is noted that vacuum packed bags, maintained in a sealed condition, may undergo volume variations if the external pressure is varied due to altitude changes.

Lace packing can produce volume reductions of 40% (39 $lbs/ft^3$) when packed by experienced men and leverage type hand tools. The bags used in this packing method strongly influences the amount of volume growth. Bags made from nylon may stretch up to 5% or 10% under the constant expansion force of the contained parachute. Other less elastic materials would be more useful, therefore, for deployment/packing bags.

Table I gives a comparison of the results obtained with the three basic packing methods.

## TABLE I

A comparison of results from the three pressure packing methods:

| METHOD | Applied Pressure Range | Maximum % Volume Reduction | Maximum * % Volume Growth | Maximum Pack Density |
|---|---|---|---|---|
| Hand Pack (uncompressed) | 1-2.5 PSIG | 0 | 0 | 21-23 $\frac{lb}{ft^3}$ |
| Mechanical | 0-200 PSIG | 50% | 15% - 30% (no restraint applied) | 42-46 $\frac{lb}{ft^3}$ |
| Vacuum | 0-15 PSIG | 25% - 30% | 0 | 30-33 $\frac{lb}{ft^3}$ |
| Lace | 0-40 PSIG (Equivalent Hydraulic) | 30% - 40% | 5% - 10% (slow growth) | 33-39 $\frac{lb}{ft^3}$ |

* During a time lapse of one hour after release of pressure.

## V. RECOMMENDATIONS FOR A CONTINUED STUDY

Four basic container shapes should be considered upon a continued pressure packing study. They are:

a. Frustrum of a cone;

b. Long cylinder;

c. Rectangular box; and

d. Short cylinder.

Several sizes of these containers are necessary to accommodate a suitable range of parachute diameters and types. Figure 27 illustrates the span of parachutes and container sizes of practical interest.

Preliminary pressure packing tests reveal a number of design considerations that should be incorporated into the packing containers. Among these are:

a. A parachute, when pressure packed into a cylindrical container is extremely difficult to remove because of side wall friction forces. To overcome this, it is necessary to design the container to open in a clam shell fashion.

b. The best relationship between the compressing piston diameter and the cylindrical container diameter should be ascertained. A close fitting piston tends to pinch the parachute being packed, while a loose fitting piston should be of a certain size relationship to the cylinder to give optimum packing. The differences between hard face pistons and hard pistons with soft rubber faces should be investigated.

c. The manner in which the pressure packing of a parachute causes the container to strain is not well defined, since the parachute under pressure acts somewhat like a fluid, and somewhat as a solid. Clarification of the parachute forces on the container is necessary for proper design. The assumption of hydrostatic pressure is usually satisfactory; however, excessively heavy containers will result in some cases.

The preliminary investigation shows the mechanical-hydraulic method of parachute pressure packing to be the most effective. On this basis, an 80-ton press was considered to be most practical for a continued study on the range of parachutes listed in Figure 27. A preliminary study of such a press was completed. Since it is not necessary to go much beyond 100 PSI to achieve maximum pack densities; the 80-ton press is considered sufficient. It is also considered desirable to use a pair of 40-ton hydraulic rams, rather than a single 80-ton press. This would provide for a more flexible packing process.

The design and closing technique of deployment bags used in pressure packing needs further improvements. Under pressure, deployment bags tend to squash and wedge against the container walls. Improved bag designs are needed to prevent such occurrences. The closing of a deployment bag so as to prevent growth after relieving the packing pressure is another design problem worthy of further effort.

## VI. DEFINITION OF TERMS

Uncompressed Volume ($V_u$): That volume which is determined by neatly folding the parachute into a container and applying a uniform piston pressure of 2.5 PSIG on the contents for one hour.

Pack Density ($\gamma_p$): The overall weight of the parachute package (W) divided by the overall volume ($V_c$) of the parachute package. ($\gamma_p = \frac{W}{V_c}$)

Hand Packing: The standard procedure of packing a parachute by hand per Government specification. A hand-packed parachute volume is equivalent to the uncompressed volume.

Pressure Packing: A method of reducing parachute package volume through the application of an external pressure.

Mechanical Packing: Pressure packing by means of a hydraulic piston or mechanical type press.

Lace Packing: Pressure packing by means of tensing circumferential laces on bag containing a parachute.

Vacuum Packing: Pressure packing by means of evacuating the air from within the parachute pack.

Effective Hydraulic Piston Pressure: That pressure found actually to be effective upon the parachute pack and differing from the applied pressure by a factor determined by the ratio of piston diameter to cylinder diameter. (See Appendix I)

Parachute Volume Reduction Factor ($\phi$): The percentage of parachute volume reduction obtained by pressure packing techniques.

$$\phi = \frac{\Delta V}{V_u} \times 100 = \frac{V_u - V_c}{V_c} \times 100$$

where $V_c$ = Compressed Volume
$\Delta V$ = Volume Reduction

# APPENDIX I

# ILLUSTRATIONS

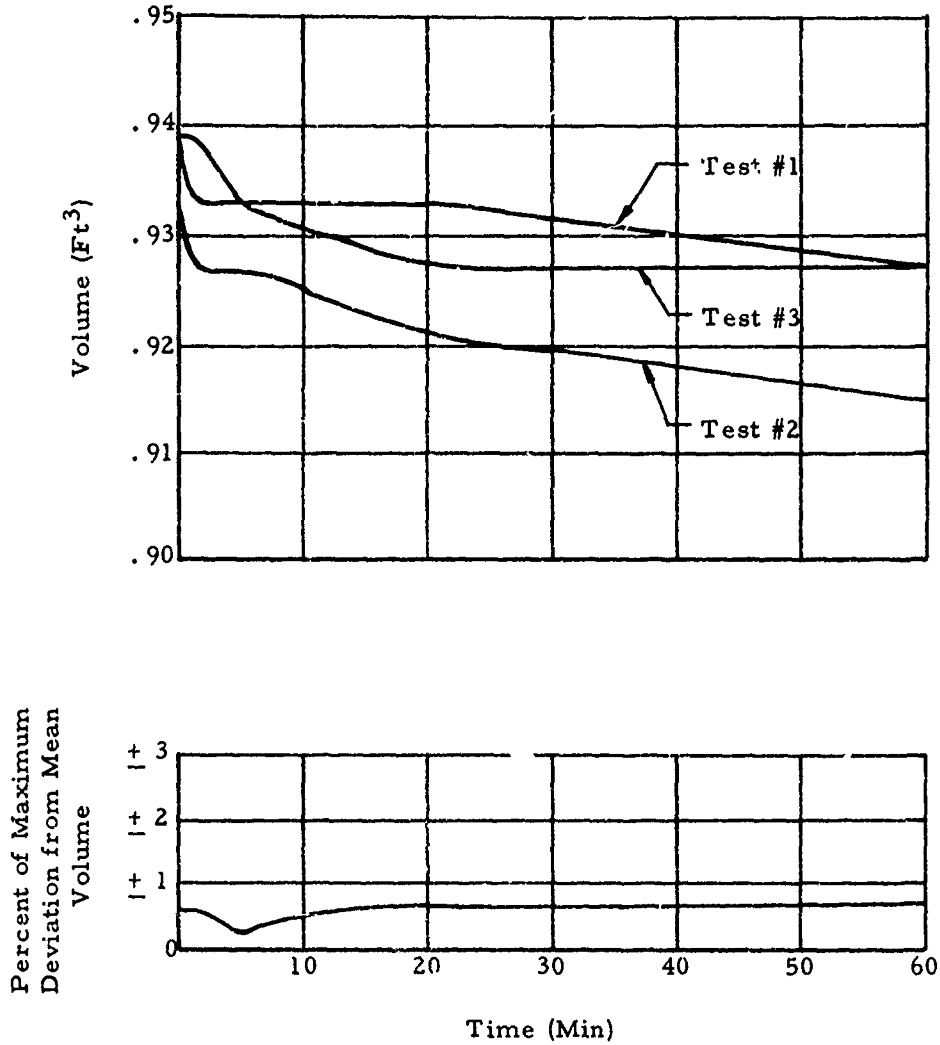



Figure 1 Uncompressed Volume Test Data, Solid Flat Parachute, 1.0 PSI

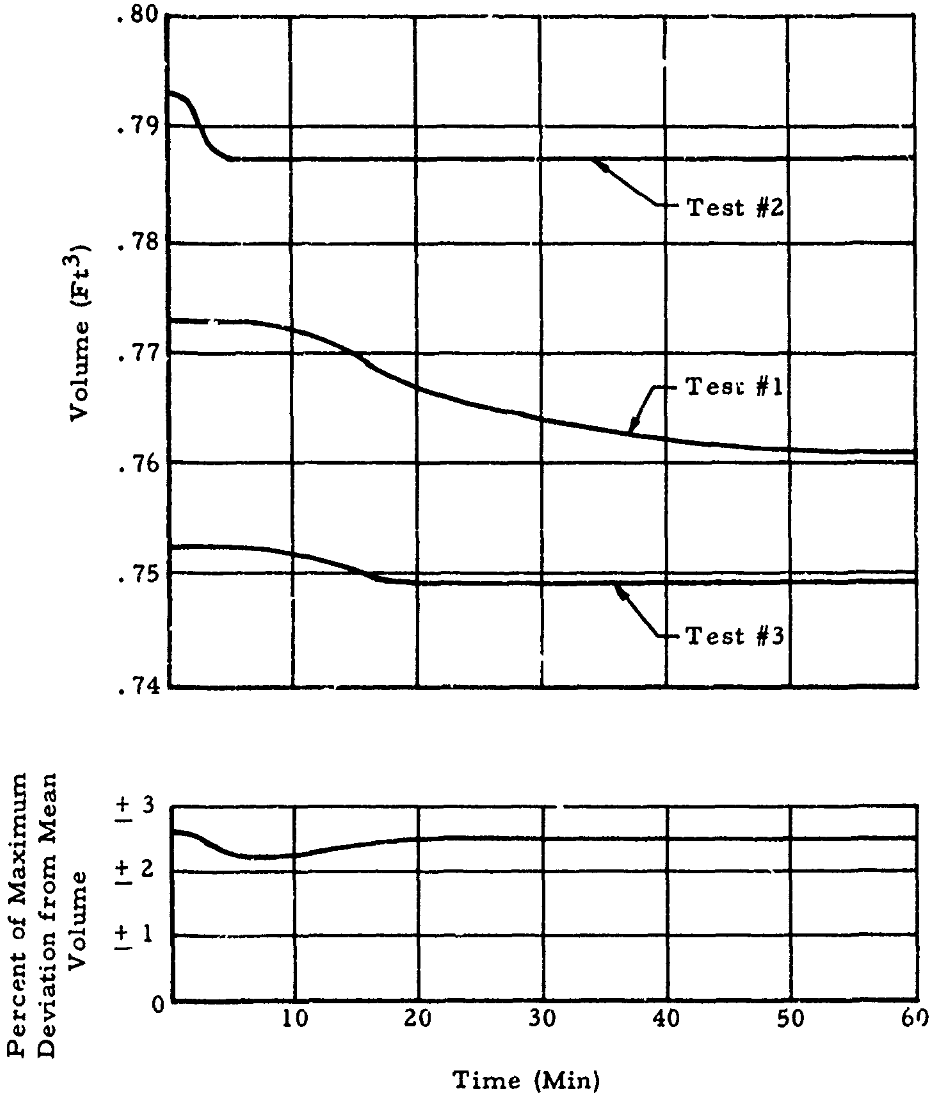



Figure 2 Uncompressed Volume Test Data. Ribbon Parachute, 1.0 PSI

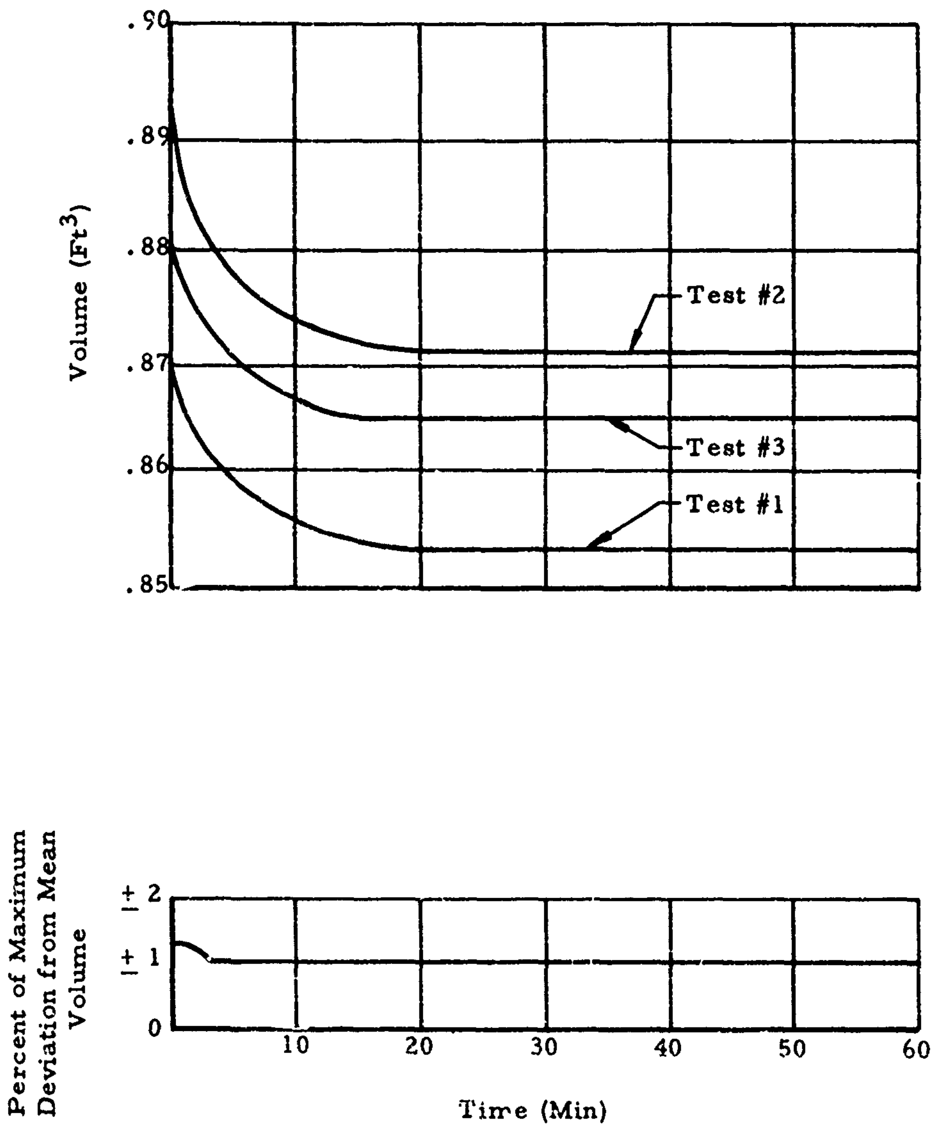



Figure 3 Uncompressed Volume Test Data, Solid Flat Parachute, 2.5 PSI

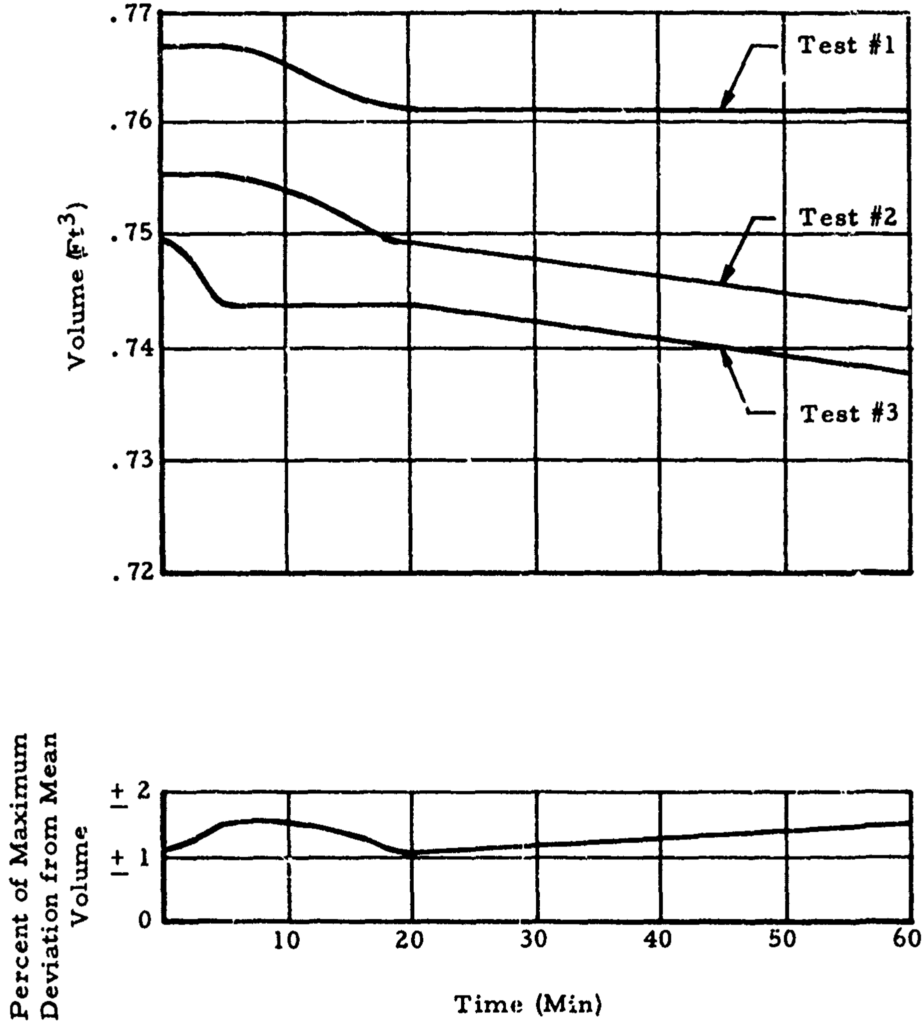



Figure 4 Uncompressed Volume Test Data, Ribbon Parachute, 2.5 PSI

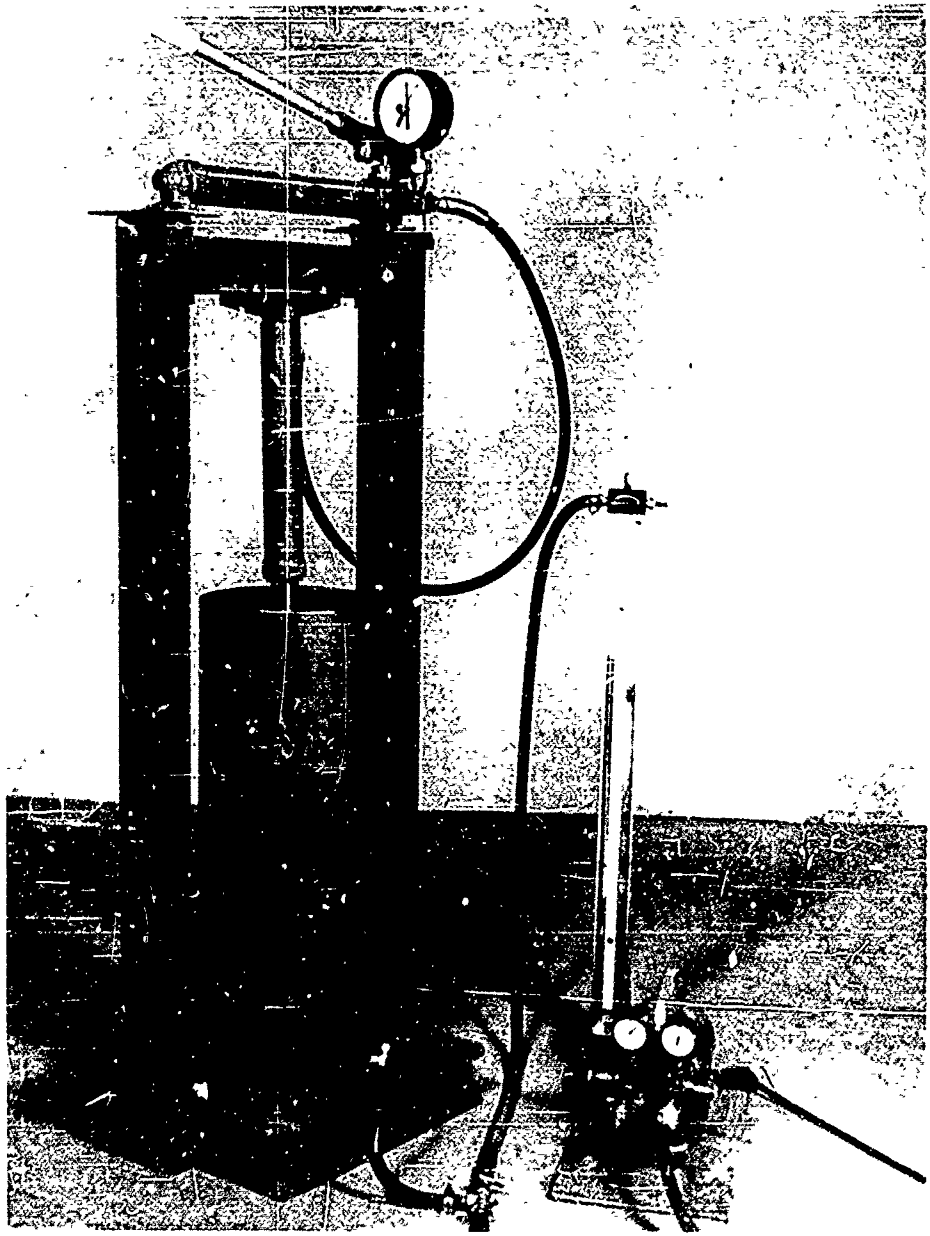


Figure 5 Mechanical Pressure Packing Equipment

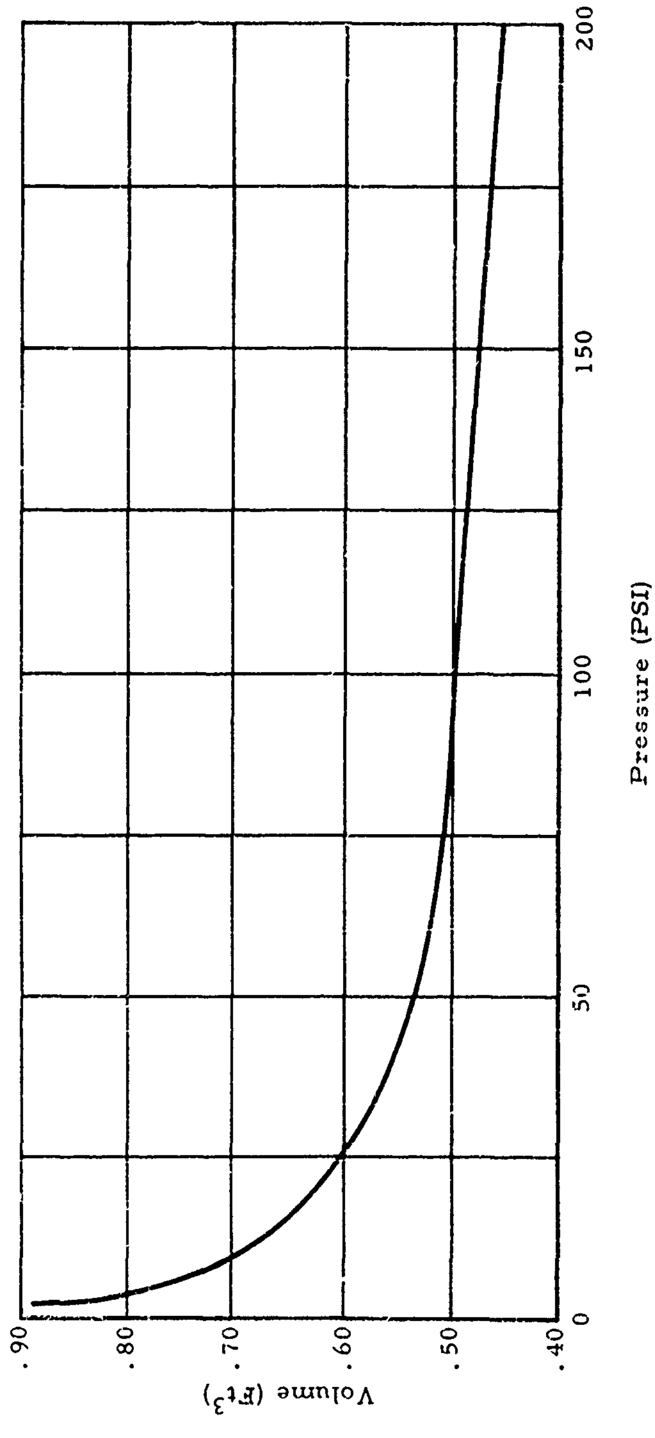



Figure 6 Pressure Packing Test Data, Solid Flat Parachute, 15-Second Increments

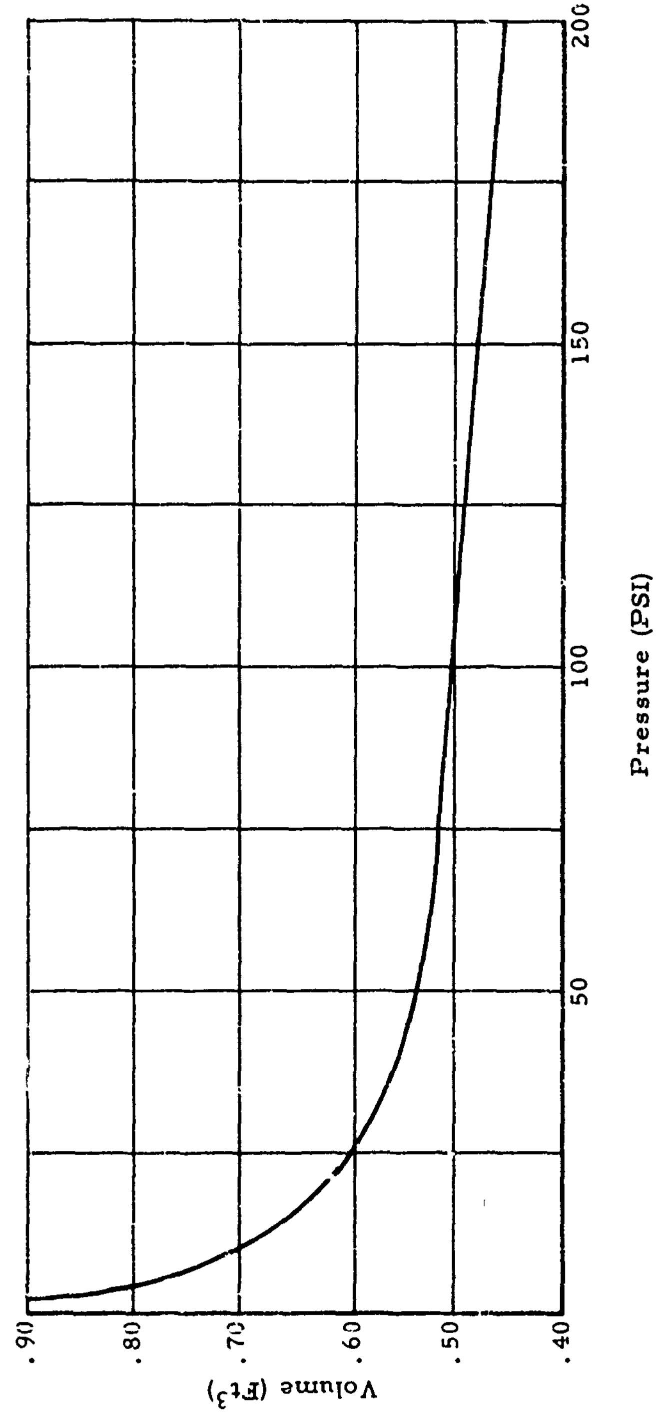



Figure 7 Pressure Packing Test Data, Solid Flat Parachute, 1-Minute Increments

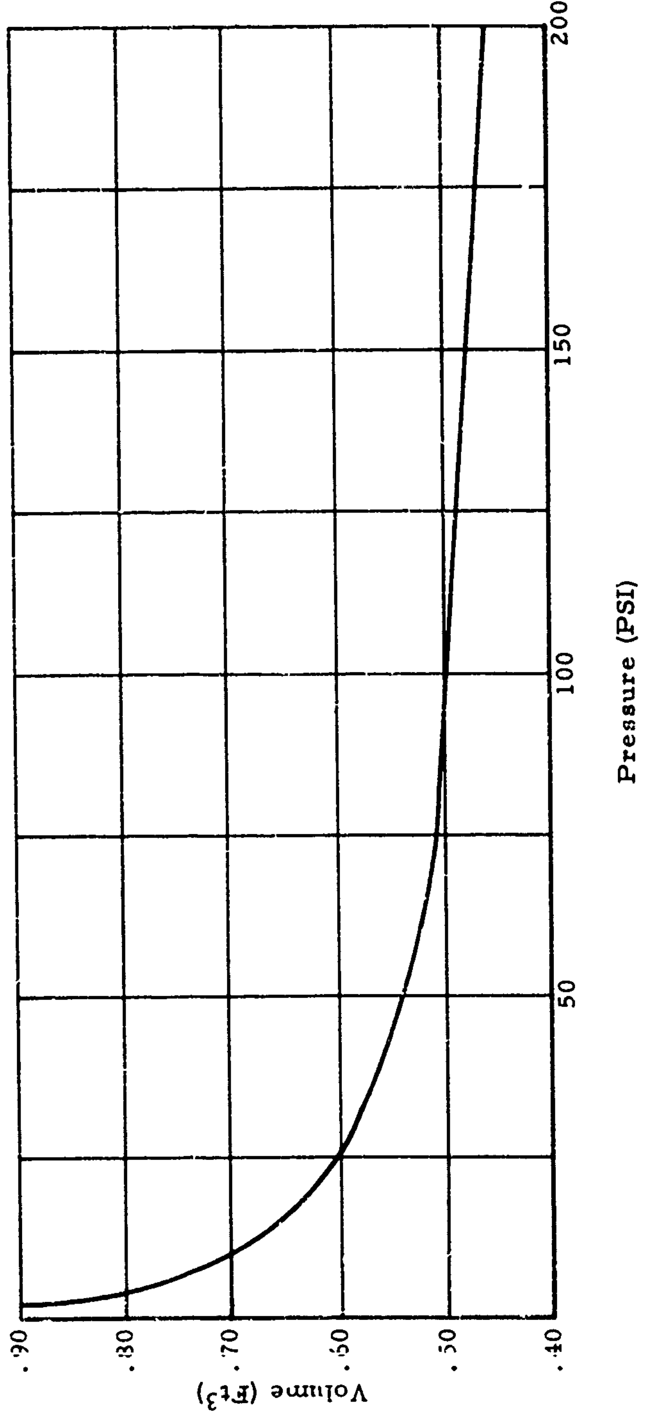



Figure 8 Pressure Packing Test Data, Solid Flat Parachute, 5-Minute Increments

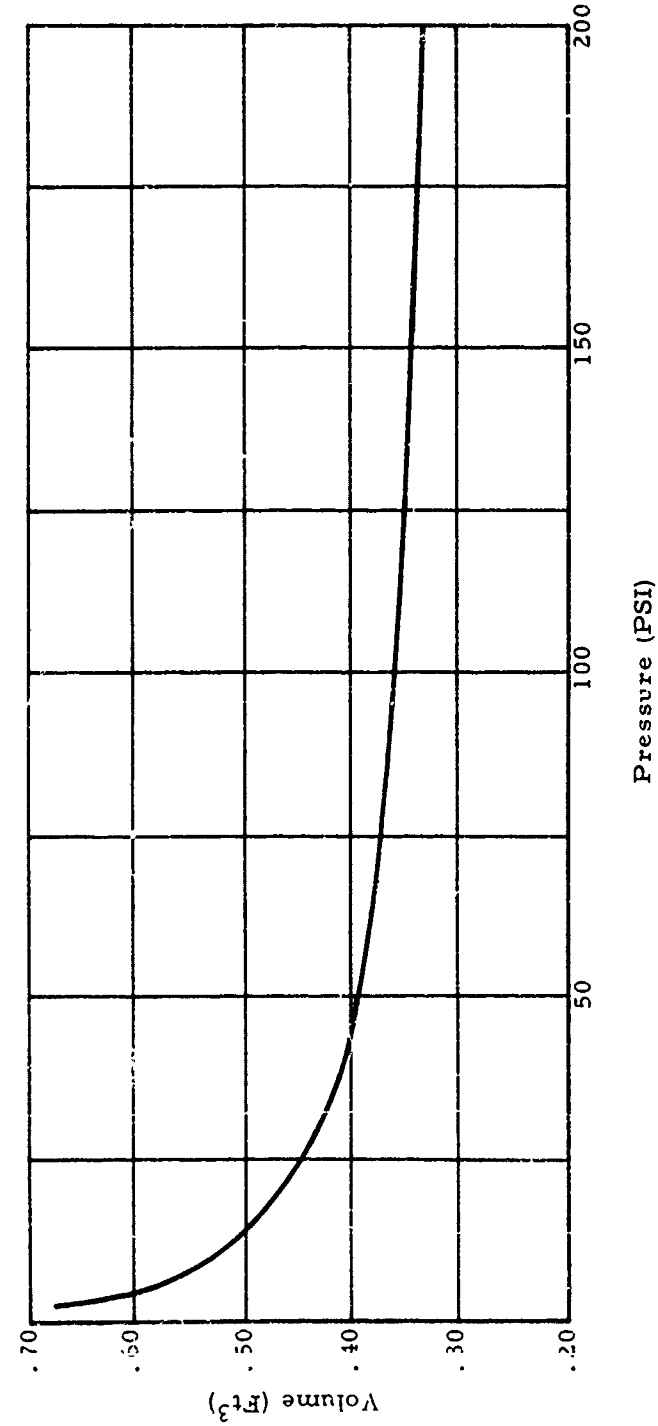



Figure 9 Pressure Packing Test Data, Ribbon Parachute, 15-Second Increments

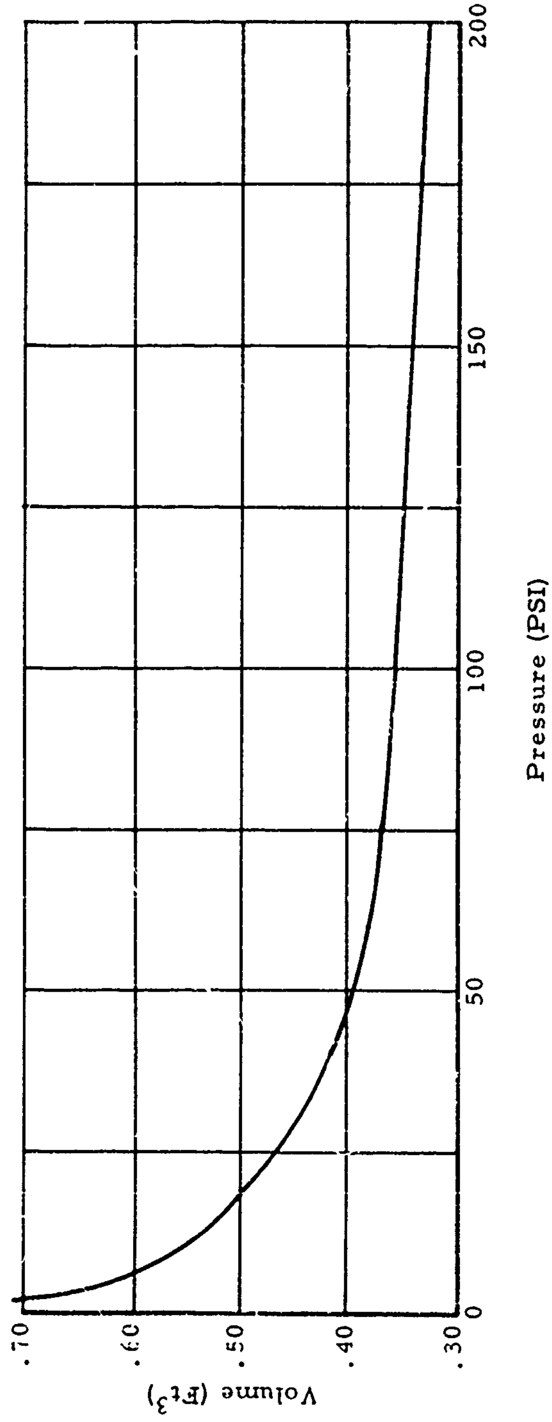



Figure 10 Pressure Packing Test Data, Ribbon Parachute, 1-Minute Increments

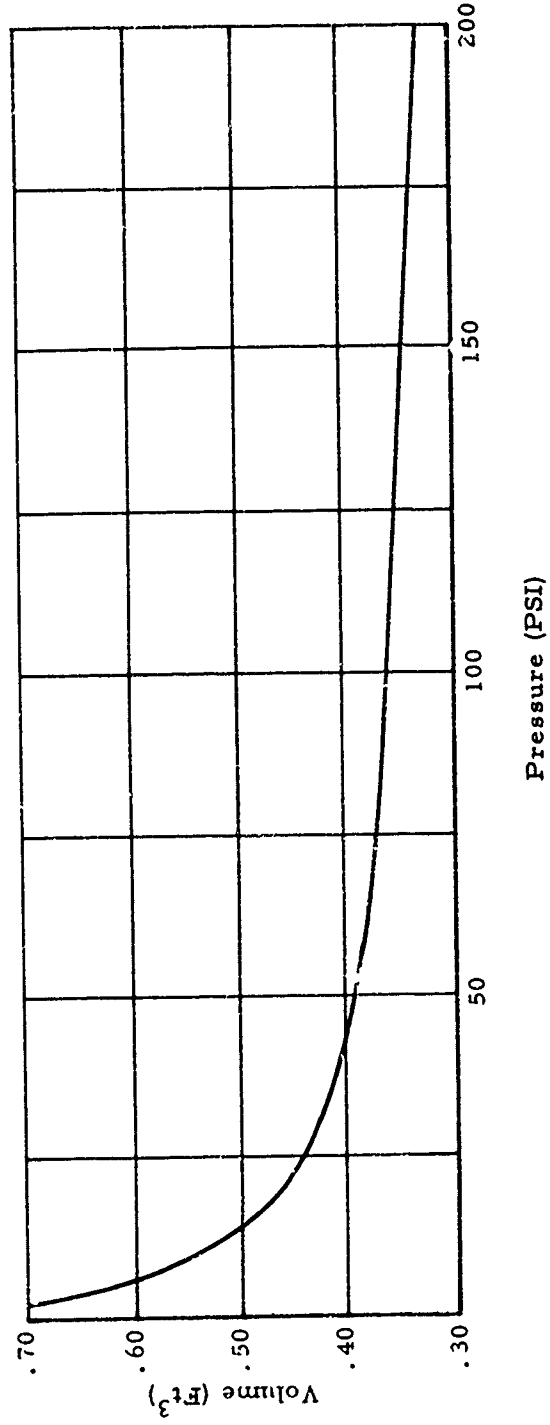



Figure 11 Pressure Packing Test Data, Ribbon Parachute, 5-Minute Increments

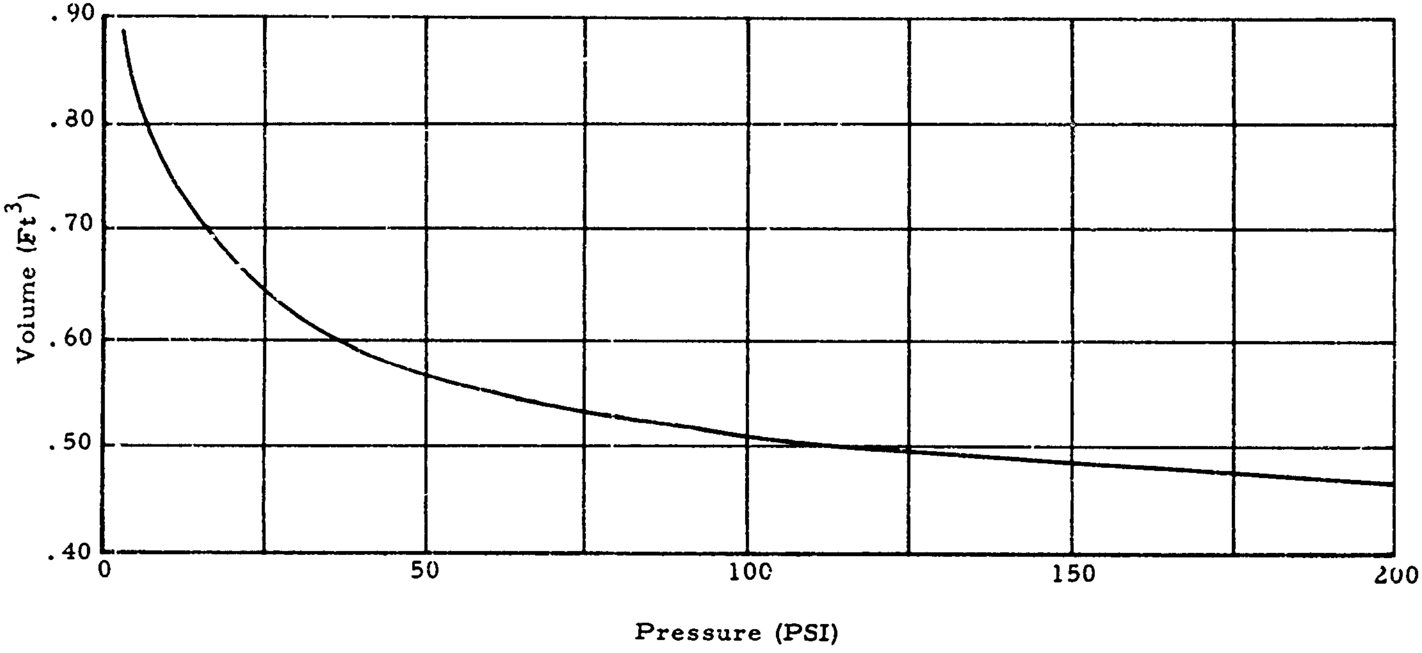



Figure 12 Test Results, Volume vs Pressure, Solid Flat Parachute

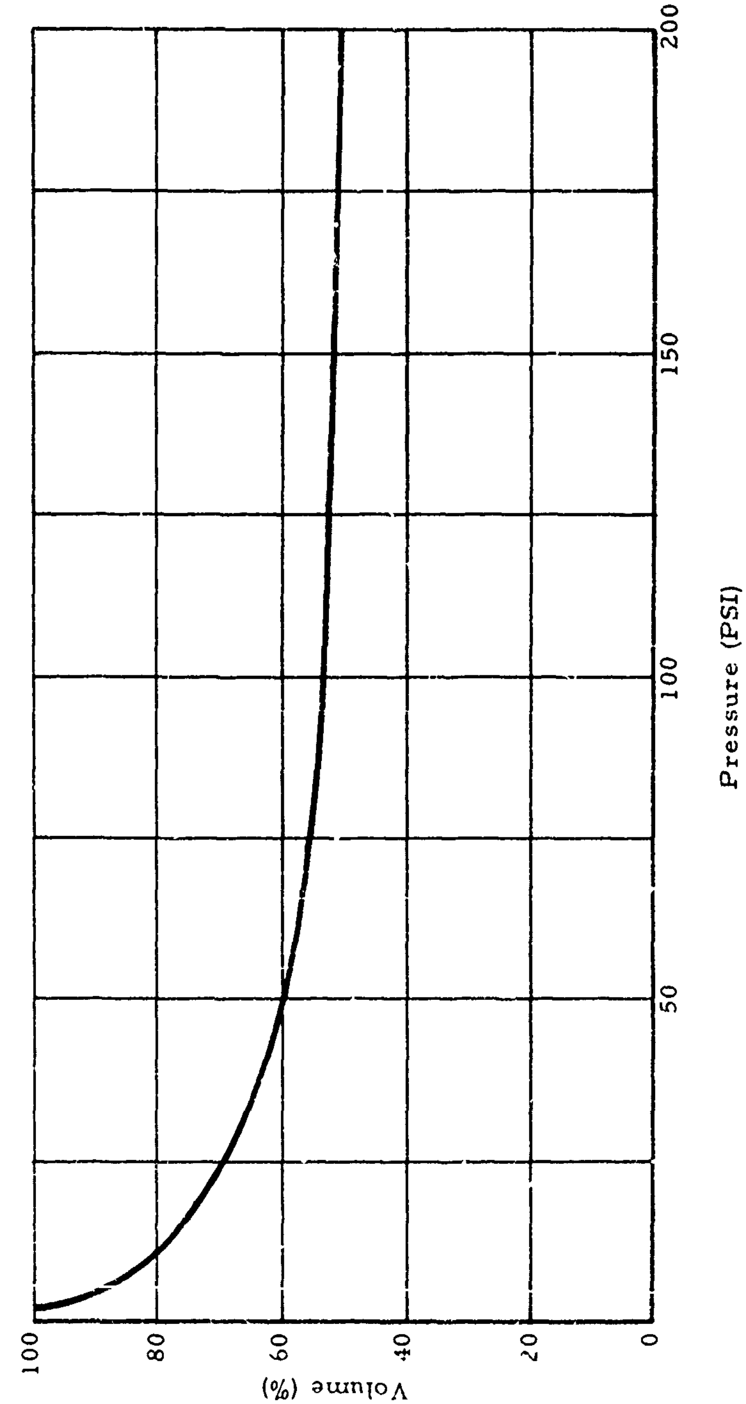



Figure 13 Test Results, Percent Volume vs Pressure, Solid Flat Parachute

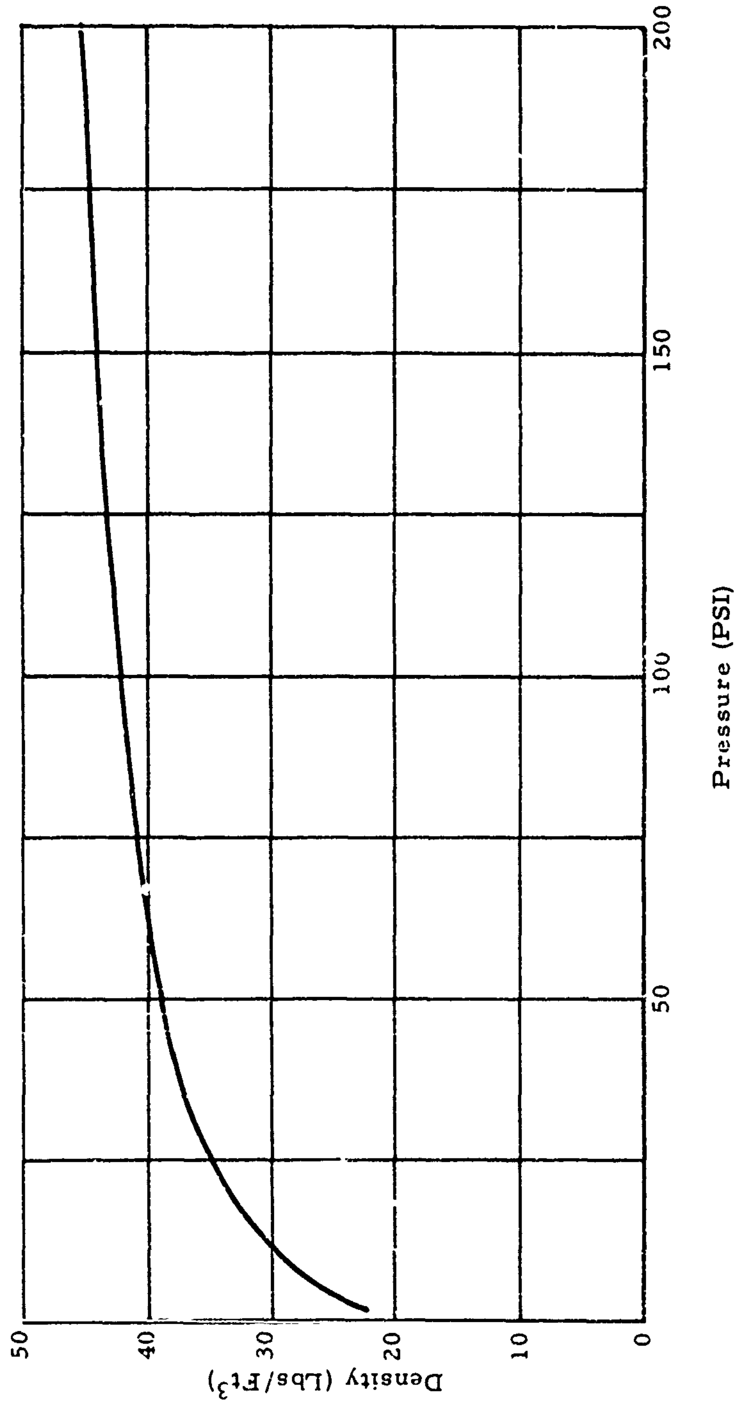



Figure 14    Test Results, Density vs Pressure, Solid Flat Parachute

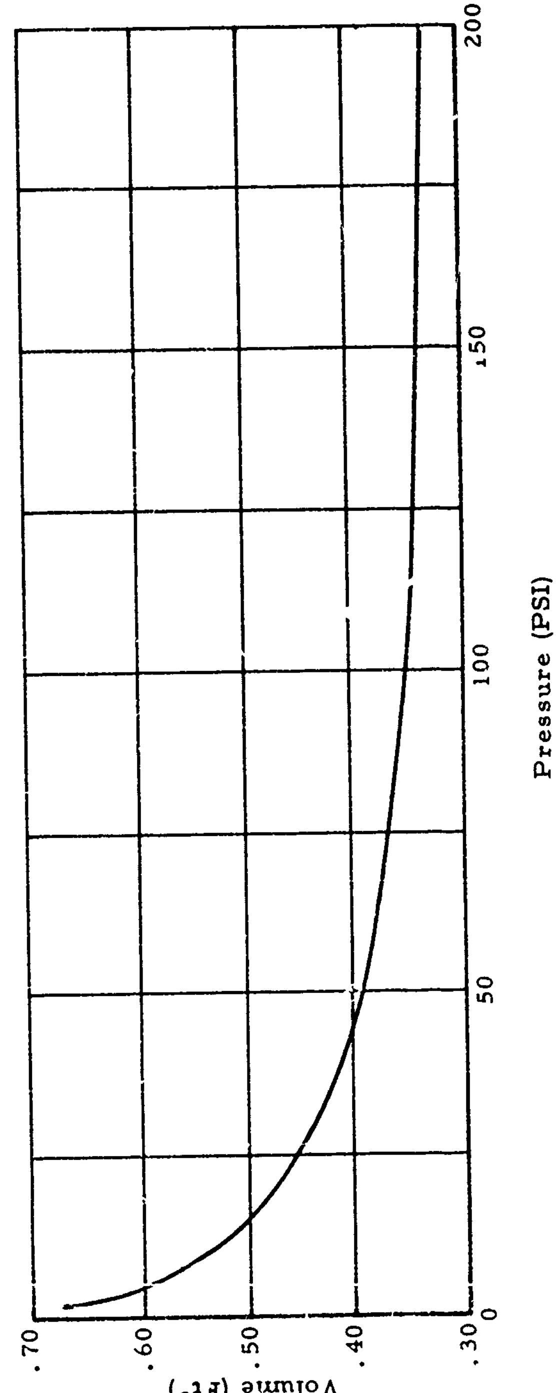



Figure 15 Test Results, Volume vs Pressure, Ribbon Parachute

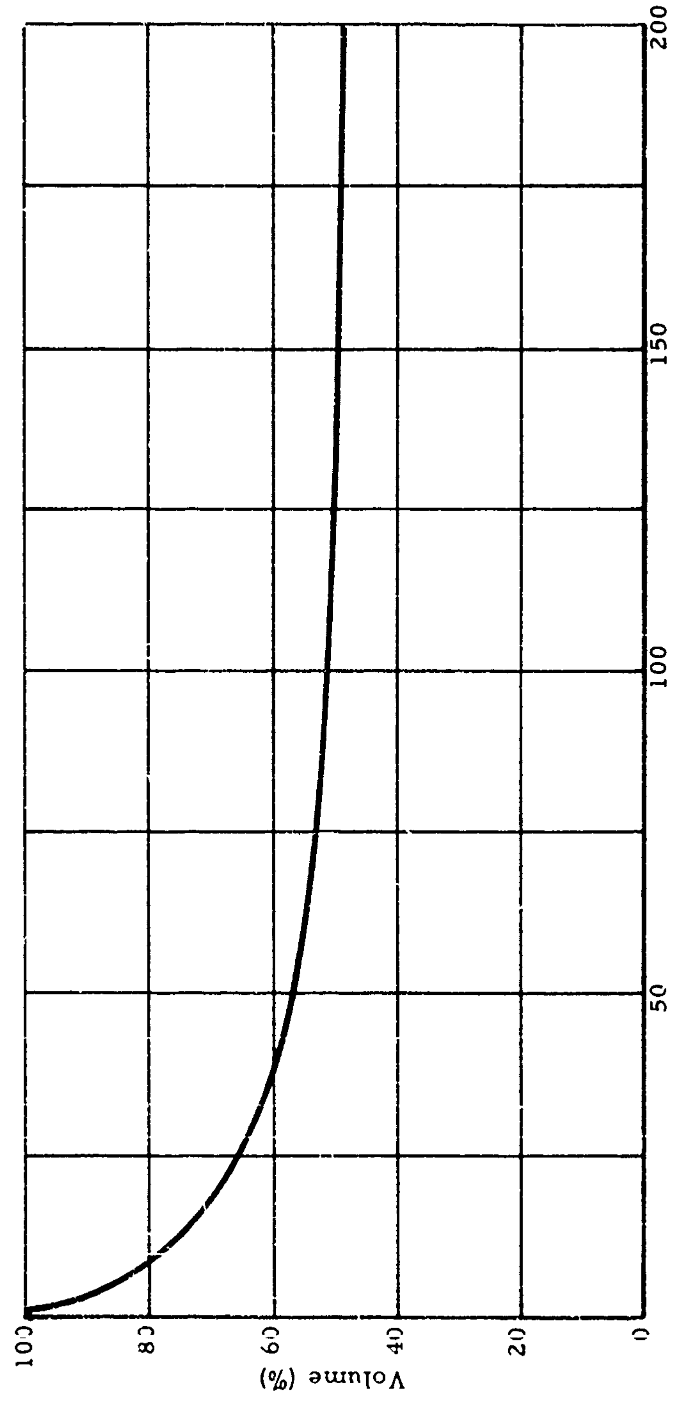



Figure 16 Test Results, Percent Volume vs Pressure, Ribbon Parachute

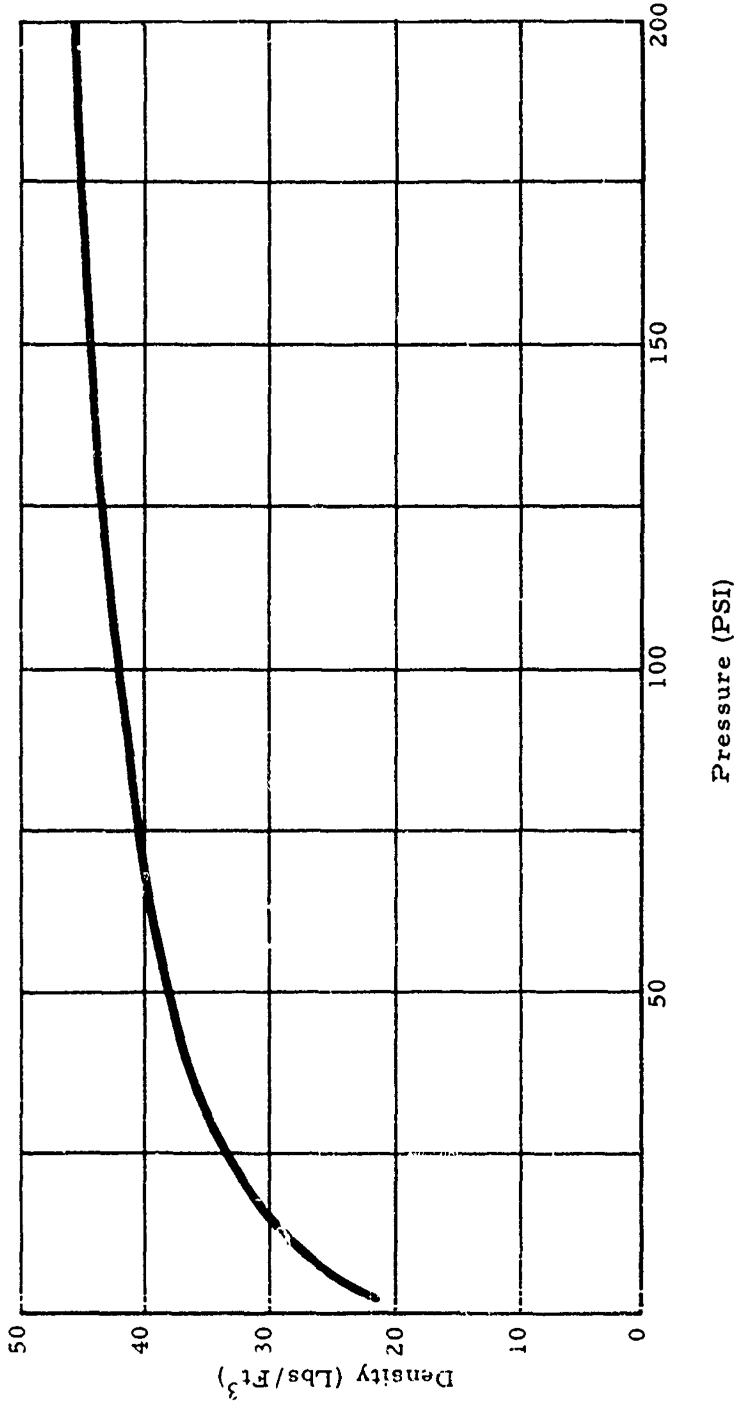



Figure 17 Test Results, Density vs Pressure, Ribbon Parachute

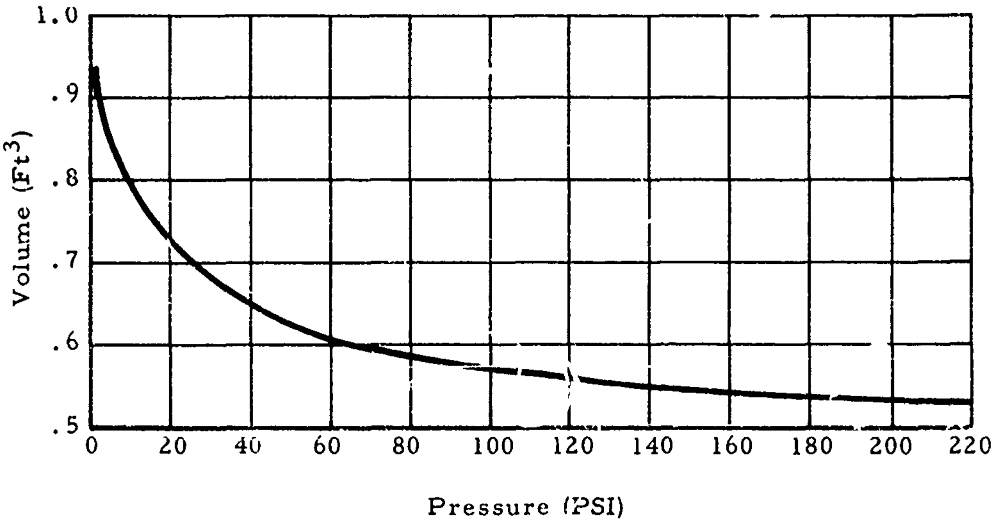



Figure 18 Test Results, Volume vs Pressure, 10-Foot Ribbon Parachute

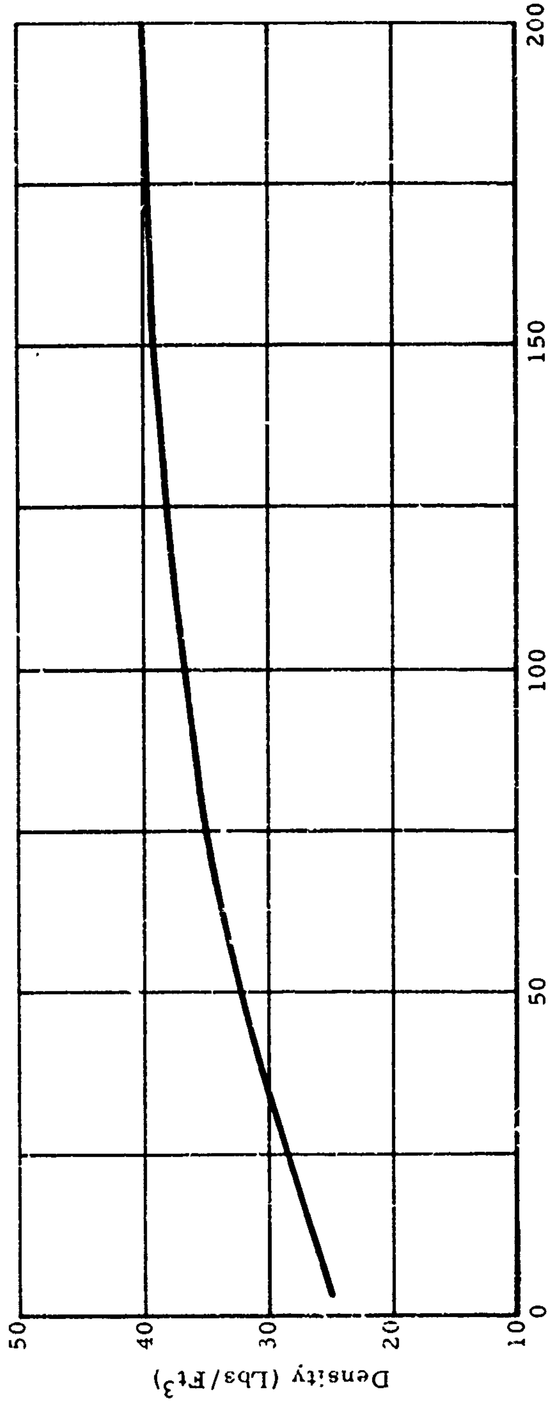
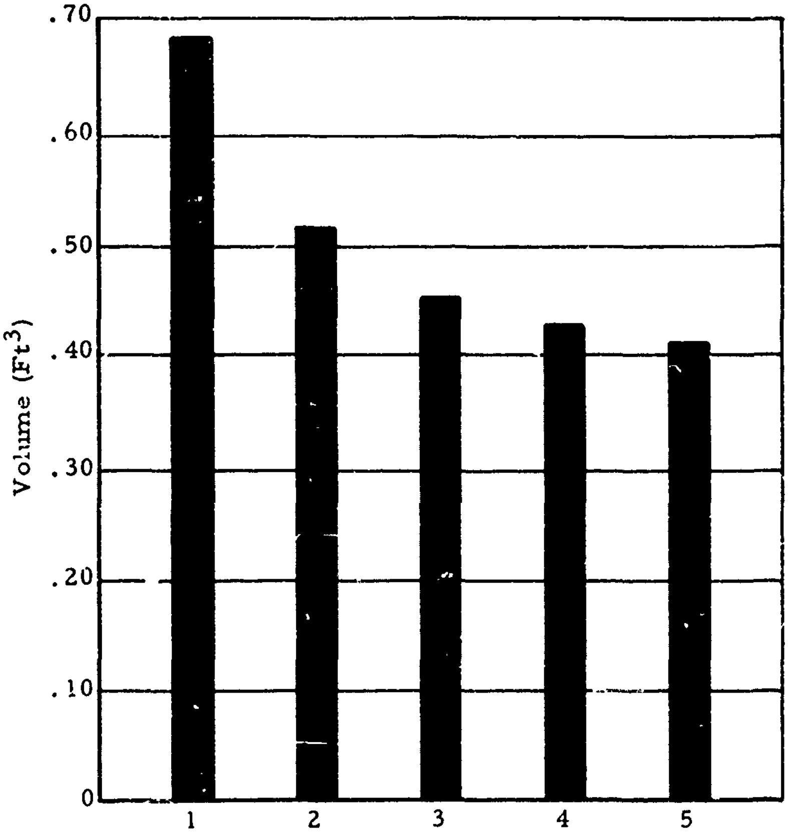
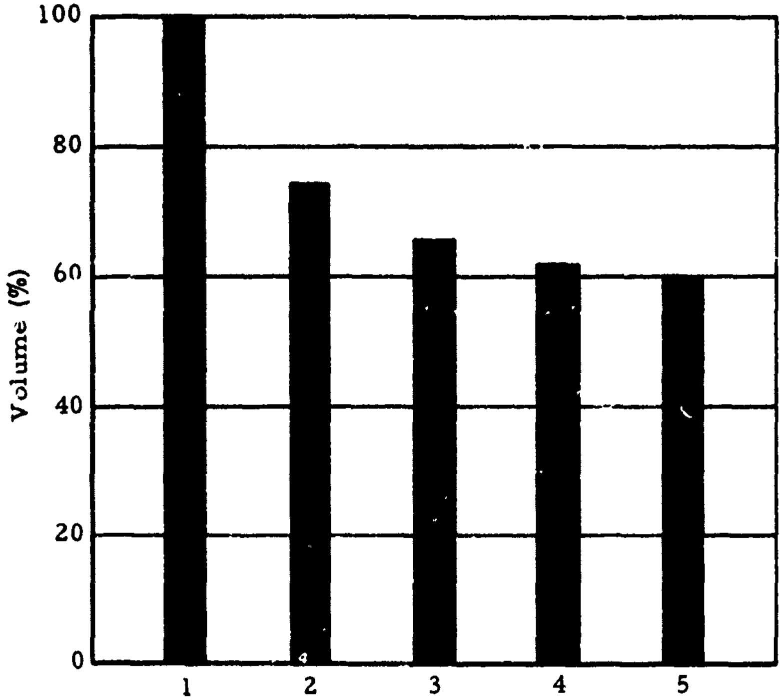



Figure 19 Test Results, Density vs Pressure, 14-Foot Ribbon Parachute



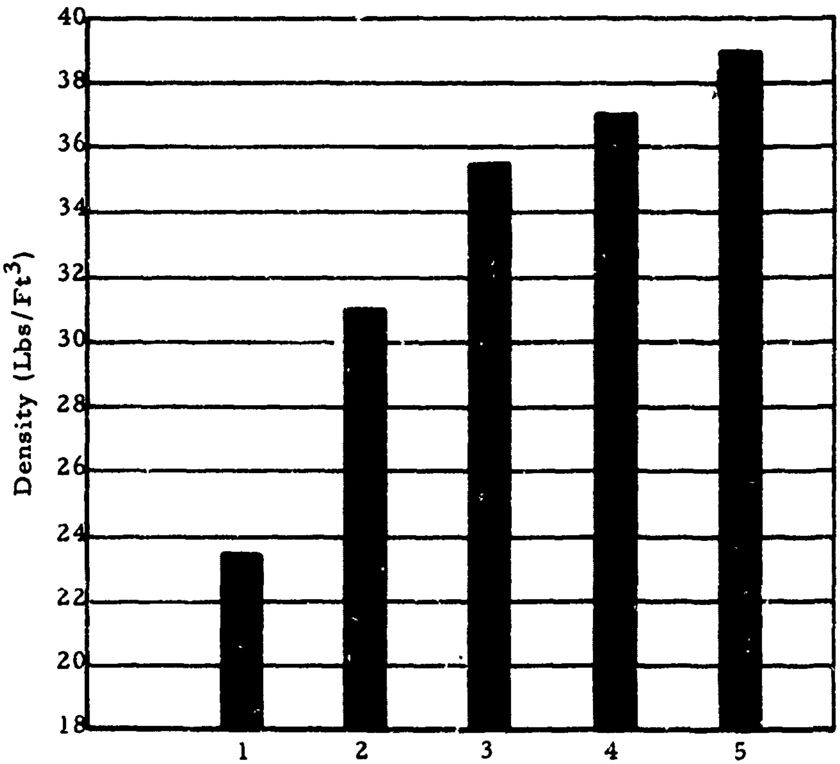

1. Hand-Packed
2. Hand Tightened by Women
3. Hand Tightened by Men
4. Tightened with Tool
5. Retightened after Overnight Set

Figure 20 Laced Pack, Volume vs Packing Method



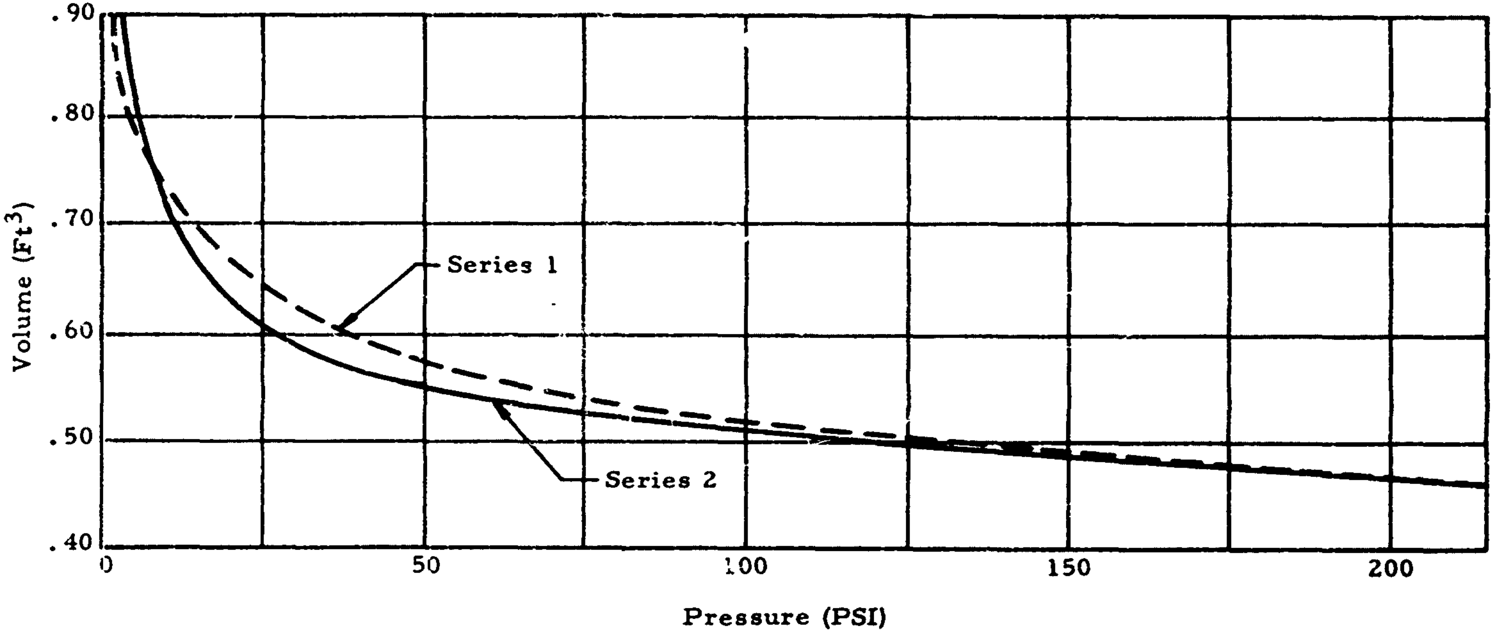

1. Hand-Packed
2. Hand Tightened by Women
3. Hand Tightened by Men
4. Tightened with Tool
5. Retightened with Tool after Overnight Set

Figure 21 Laced Pack, Percent Volume vs Packing Method




1. Hand-Packed
2. Hand Tightened by Women
3. Hand Tightened by Men
4. Tightened by Tool
5. Retightened after Overnight Set

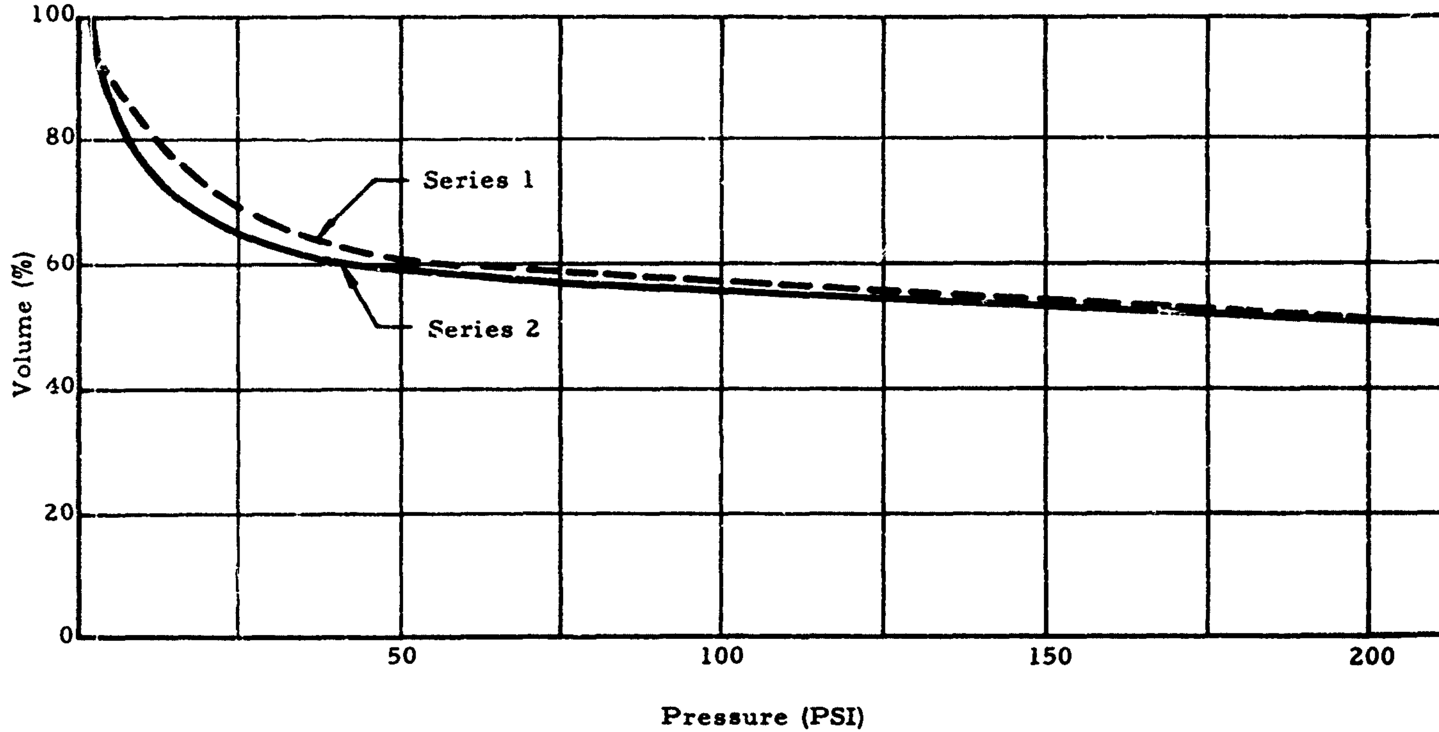
Figure 22 Laced Pack, Density vs Packing Method




Series 1, $P_{mech}$ to 2.5 PSI; $P_{vac}$ to 12 PSI, $P_{mech}$ to 212 PSI

Series 2, $P_{mech}$ to 200 PSI; $P_{mech}$ and $P_{vac}$ to 212 PSI

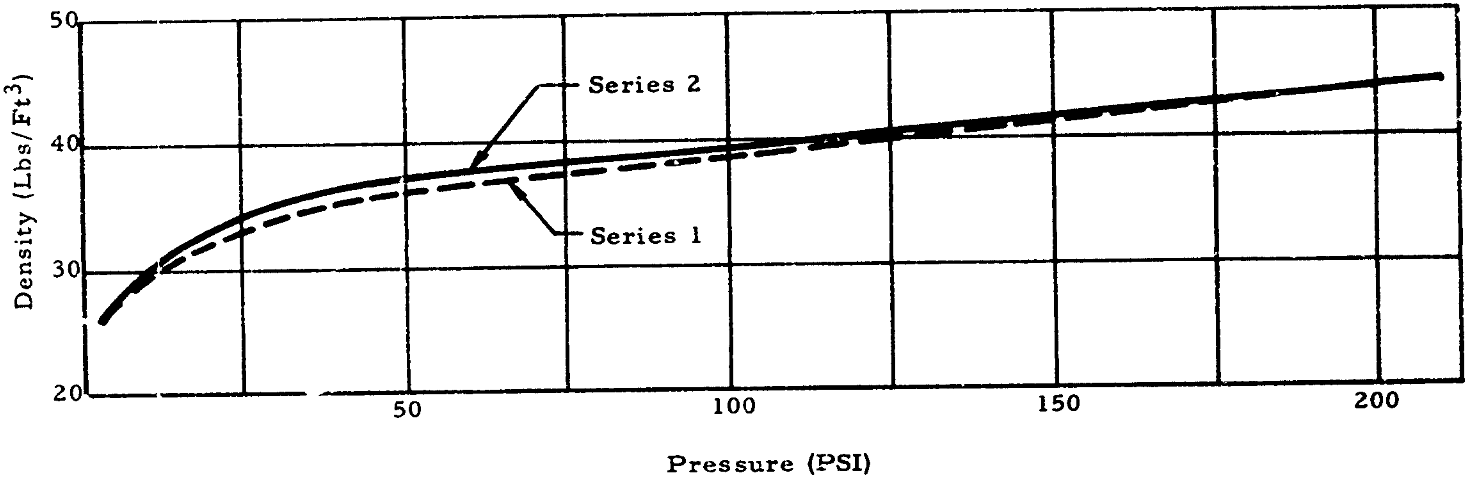
Figure 23 Combined Mechanical and Vacuum Pressure Packing, Volume vs Pressure




Series 1, $P_{mech}$ 0-2.5 PSI; $P_{vac}$ 2.5-12 PSI; $P_{mech}$ 12-212 PSI

Series 2, $P_{mech}$ 0-200 PSI; $P_{vac}$ and $P_{mech}$ 200 to 212 PSI

Figure 24 Combined Mechanical and Vacuum Pressure Packing, Percent Volume vs Pressure




Series 1, $P_{mech}$ 0-2.5 PSI; $P_{vac}$ 2.5 - 12.0; $P_{mech}$ and $P_{vac}$ 12.0 to 212 PSI

Series 2, $P_{mech}$ 0-200 PSI; $P_{mech}$ and $P_{vac}$ 200-212 PSI

Figure 25 Combined Mechanical and Vacuum Pressure Packing, Density vs Pressure

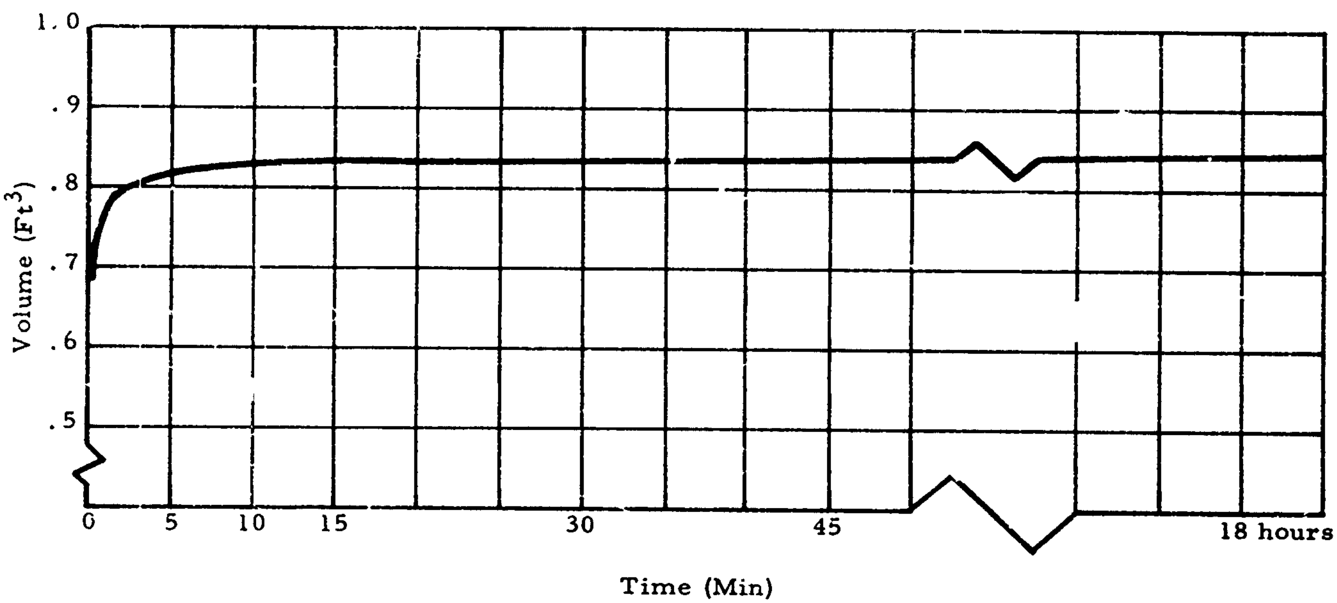
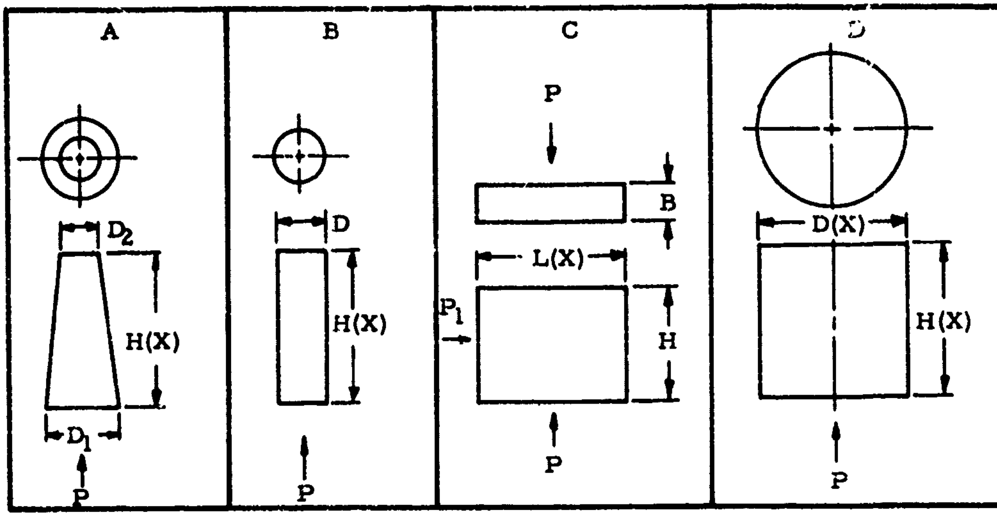


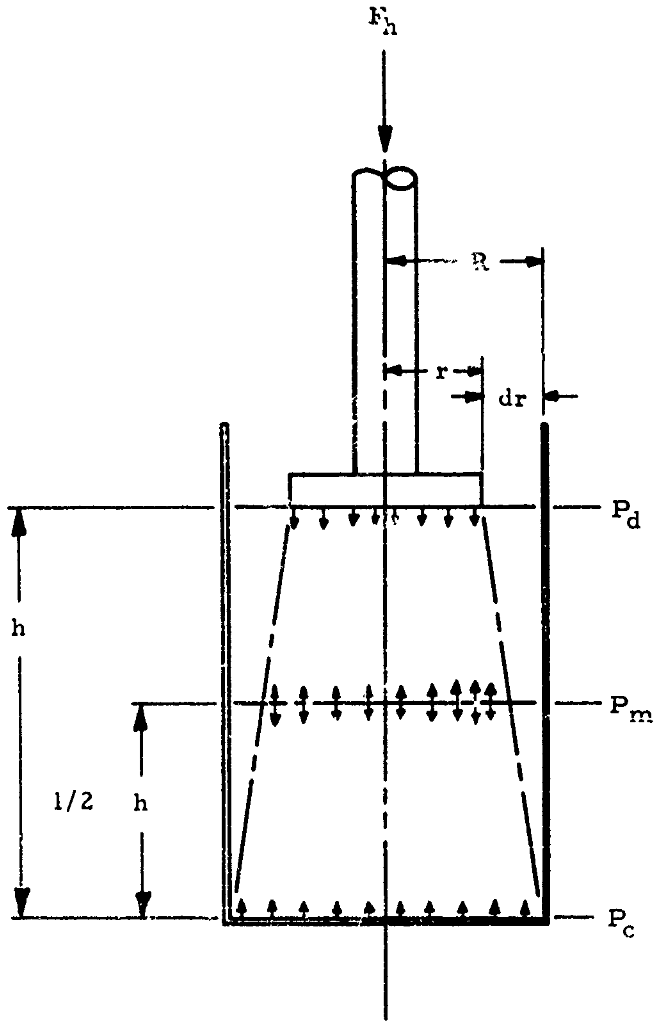

Figure 26 Mechanical Pack, Growth vs Time, 10-Foot Ribbon Parachute




P - Denotes direction of pressure application.
X - Denotes basic dimension of container ratio.

| CONTAINERS REQUIRED | PARACHUTE TYPES | VOLUME CUBIC FEET | CONTAINER TYPE AND DIMENSIONS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | A | | | B | | C | | | D | |
| | | | H | $D_1$ | $D_2$ | H | D | L | B | H | H | D |
| Set No. 1 | 22 ft diameter Ring Slot | 1.5 | X | $\frac{X}{2}$ | $\frac{X}{4}$ | X | $\frac{X}{3}$ | X | $\frac{X}{4}$ | $\frac{X}{1.3}$ | X | X |
| | | | 28 | 14 | 7 | 31 | 10 | 24 | 6 | 18 | 15 | 15 |
| Set No. 2 | 14 ft diameter Ribbon | 3.5 | X | $\frac{X}{2.1}$ | $\frac{X}{3.8}$ | X | $\frac{X}{2.4}$ | X | $\frac{X}{4}$ | $\frac{X}{1.6}$ | X | $\frac{X}{0.8}$ |
| | | | 38 | 18 | 10 | 35.5 | 14.7 | 34 | 8.5 | 21 | 17.5 | 21 |
| | G-2 64 ft dia. Solid Canopy | 5.0 | X | $\frac{X}{2.4}$ | $\frac{X}{3.8}$ | X | $\frac{X}{3.4}$ | X | $\frac{X}{4}$ | $\frac{X}{1.1}$ | X | $\frac{X}{1.2}$ |
| | | | 48.7 | 20 | 10 | 50.5 | 14.7 | 34 | 8.5 | 30 | 25 | 21 |
| Set No. 3 | 64 ft diameter Ribbon | 21.0 | X | $\frac{X}{2}$ | $\frac{X}{4}$ | X | $\frac{X}{3}$ | X | $\frac{X}{4}$ | $\frac{X}{1.3}$ | X | X |
| | | | 68 | 34 | 17 | 75 | 25 | 58 | 14.5 | 29 | 36 | 36 |

Figure 27 Pressure Packing Container Ratio and Dimensions




Disc Pressure $= P_d = \frac{F_h}{\pi r^2}$

Mean Pressure $= P_m = \frac{P_d + P_c}{2}$

Cylinder Pressure $= P_c = \frac{F_h}{\pi R^2}$

Figure 28 Mechanical Packing Pressure Distribution

## APPENDIX II

## EFFECTIVE PACKING PRESSURE

Ideally, it would be desirable to have the effective piston diameter of a hydraulic ram being used for pressure packing of parachutes to be equal to the internal packing cylinder diameter. If this were true, then the effective packing pressure would be equal to the applied pressure or the applied force divided by the piston area. However, experimental results indicate that close fits between the piston or compression disc, if one is used, and the cylinder walls can cause damage to the parachute as a result of pinching between the disc and the cylinder walls. Such a condition can be avoided by allowing clearance to exist around the piston. The amount of this clearance should, of course, be kept to a minimum since the effective packing pressure will become difficult to determine.

From Figure 28 the mean internal or effective pressure, $P_m$, can be assumed to be:

$$P_m = \frac{P_d + P_c}{2} \qquad (1)$$

where $P_d$ = disc unit pressure based upon the applied force, $F_h$.

$P_c$ = cylinder cross-section unit pressure based upon applied force, $F_h$.

The data presented in this report are based upon the assumption that the parachute packing pressure, P. is equal to the disc unit pressure, $P_d$. The error introduced by such an assumption is small since for all tests the disc area was kept as close to the cylinder area as practical. For a more detailed study, the more exact pressure, $P_m$, should be used.

Referring to Figure 28, the error, E, introduced by using $P_d$ can be expressed by:

$$E = \frac{P_m - P_d}{P_m} \qquad (2)$$

which, by substitution, becomes:

$$E = \frac{P_c - P_d}{P_d + P_c} \qquad (3)$$

now since $P_c = \frac{Fh}{\pi R^2}$ and $P_d = \frac{Fh}{\pi r^2}$, then

$$E = \frac{R^2 - r^2}{R^2 + r^2} \tag{4}$$

Aeronautical Systems Division, Dir/Aeromechanics, Flight Accessories Lab, Wright-Patterson AFB, Ohio.
Rpt Nr ASD-TR-61-426. STUDY OF PRESSURE PACKING TECHNIQUES FOR PARACHUTES. Final report, June 62, 47p. incl illus., table.

Unclassified Report

This report summarizes the results of a parachute pressure packing investigation designed to find optimum parachute volume reduction techniques. Included are a description of the test equipment and a discussion of the influence of parachute types, time rate of pressure application and container shapes on the pack density. The results are presented

( over )

1. Parachutes
2. Pressure packing

I. AFSC Project 8151, Task 60151
II. Contract AF 33(600)-39643
III. Space Recovery Systems, Inc., El Segundo, Calif.
IV. SRS-616
V. Not aval fr OTS
VI. In ASTIA collection

in graph form.
The study revealed that pressure packing using a mechanical press can reduce the volume of a good hand-packed parachute by approximately fifty percent under application of about 100 PSIG of pressure. This results in a pack density of 45 pounds per cubic foot. The obtained pack densities are independent of parachute type and time rate of pressure application.

Aeronautical Systems Division, Dir/Aeromechanics, Flight Accessories Lab, Wright-Patterson AFB, Ohio.
Rpt Nr ASD-TR-61-426. STUDY OF PRESSURE PACKING TECHNIQUES FOR PARACHUTES. Final report, June 62, 47p. incl illus., table.

Unclassified Report

This report summarizes the results of a parachute pressure packing investigation designed to find optimum parachute volume reduction techniques. Included are a description of the test equipment and a discussion of the influence of parachute types, time rate of pressure application and container shapes on the pack density. The results are presented

( over )

1 Parachutes
2. Pressure packing

I. AFSC Project 8151, Task 60151
II. Contract AF 33(600)-39643
III. Space Recovery Systems, Inc., El Segundo, Calif.
IV. SRS-616
V. Not aval fr OTS
VI In ASTIA collection

in graph form.
The study revealed that pressure packing using a mechanical press can reduce the volume of a good hand-packed parachute by approximately fifty percent under application of about 100 PSIG of pressure. This results in a pack density of 45 pounds per cubic foot. The obtained pack densities are independent of parachute type and time rate of pressure application.